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DEVICES FOR ONBOARD TREATMENT OF WASTES FROM VESSELS

Thomas J. O'Grady, et al

Thiokol Corporation

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A program involving the demonstration of a pleasure craft zero discharge, physical/chemical waste treatment system employing a unique filter-incinerator device was conducted. Extensive test data from laboratory and shipboard demonstration tests of the system are presented. Data on manufacture and installation costs for the pleasure craft are also presented. The program demonstrated the ability to zero discharge waste and comply with the 23 June 1972 EPA no-discharge standard. This report was submitted in fulfillment of Contract 68-01-0115, under the sponsorship of the Environmental Protection Agency.

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DEVICES FOR ONBOARD TREATMENT OF WASTES FROM VESSELS

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FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise, and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment--air, water, and land.

The National Environmental Research Centers provide the multidisciplinary focus through programs engaged in

- Studies on the effects of environmental contaminants on man and biosphere, and
- A search for ways to prevent contamination and to recycle valuable resources.

The research and development effort described in this report involved demonstration of a sanitary waste treatment system which prevented the discharge of pollutants into the surrounding environment.

A. W. Breidenbach, Ph.D.
Director
National Environmental
Research Center,
Cincinnati, Ohio

ABSTRACT

A program involving the demonstration of a pleasure craft zero discharge, physical/chemical waste treatment system employing a unique filter-incinerator device was conducted. Extensive test data from laboratory and shipboard demonstration tests of the system are presented. Data on manufacture and installation costs for the pleasure craft system are also presented.

The program demonstrated the ability to zero discharge waste and comply with the 23 Jun 1972 EPA no-discharge standard.

This report was submitted in fulfillment of Contract 68-01-0115, under the sponsorship of the Environmental Protection Agency.

CONTENTS

Section Page

ABSTRACT iv

List of Figures vi
List of Tables viii
Acknowledgements ix

I CONCLUSIONS 1

II RECOMMENDATIONS 2

III INTRODUCTION 3

IV SYSTEM DEVELOPMENT 7

Program Description 7
Phase I - Laboratory Test Program 8
  Design Objectives 8
  Filter-Incinerator Development 8
  Improved Design 14
  Secondary Treatment 25

V SYSTEM DEMONSTRATION 32

Flow-Thru Tests 32
Zero Discharge Tests 39
Preliminary Phase II Design 41
  System Design 42
  Laboratory Test Phase 46
  Field Testing 61
  Fuel Oil Tests 72

VI SYSTEM ECONOMICS 77

VII COAST GUARD REVIEW 79

APPENDIX I--Summary of Filter-Incinerator Tests. . 80

APPENDIX II--Identification of Organic Compounds in a Closed-Loop Hypochlorite Wastewater Treatment System 89

FIGURES

No.		Page
1	Small Pleasure Boat Waste Treatment System	5
2	Houseboat Waste Treatment System Flow Diagram ...	6
3	Filter-Incinerator Design (Packed Bed)	10
4	Flow Diagram and Equipment for Filter-Incinerator Tests	11
5	Profile of Filter-Incinerator Temperature and Bed Pressure (Test 2)	15
6	Filter-Incinerator Cylindrical Test Unit for Cloth Media	16
7	Glass Cloth Test Rig	17
8	Glass Cloth Filter	21
9	Refrasil Filter, Before Test	22
10	Refrasil Filter, After 40 Cycle Test	23
11	Catalyst Calibration Data - Static Reactor (65°-70°F) ..	27
12	Catalyst BOD Reduction, Ambient Temperature, Static Reactor (WNC-1 Catalyst)................	28
13	Effect of WNC-1 Catalyst on BOD and SS Removal	30
14	Effect of WNC-1 Catalyst on Cl_2 Removal	31
15	Building M-85 Layout, EPA Houseboat	33
16	Houseboat Schematic Diagram	34
17	Prototype Filter-Incinerator Assembly	35
18	Typical Temperature Profile	39

FIGURES (Cont)

No.		Page
19	Zero Discharge Installation Layout	43
20	Catalytic Tank Support	44
21	Incinerator Blower Assembly	47
22	Treatment of 24-1/2 Gal Sewage With a 100 In^2 PEPCON Cell at a Nominal of 1 Amp/In^2	55
23	Houseboat Waste Treatment System Installed in Closet	60
24	Thiokol Houseboat	62
25	Thiokol Houseboat Waste Treatment System Installation	63
26	Houseboat Waste Treatment System Closeup	64
27	Houseboat Waste Treatment System Electrical Schematic	65
28	Hot Gas Duct and Mounting Flange, Right Three-Quarter View	73
29	Hot Gas Duct and Mounting Flange, Left Three-Quarter View	74
30	Fuel Oil Delivery Rate vs Fuel Pump Pressure for 0.50, 0.60, and 0.65 gph Nozzles	76

TABLES

No.		Page
1	Design Objectives	9
2	Composition of 10 In. Diameter Filter Column	12
3	10 In. Diameter Filter-Incinerator Testing	13
4	Filter Material Evaluation	18
5	Major Flow-Thru System Components	36
6	Summary of System Flow-Thru Testing	37
7	Projected Flow-Thru System Performance	40
8	Zero Discharge Operation Log	50
9	Zero Discharge Analytical Results, Treatment Tank	51
10	Zero Discharge Operation Log, Test Configuration III	53
11	Zero Discharge Operation Log, Test Configuration IV	56
12	Analysis of Treatment Tank Sludge	57
13	Houseboat System Flush Liquid	59

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This program which extended over a period of 30 months was accomplished with the cooperation of many individuals in the Government and the contractor organizations.

The support and guidance of the EPA, Edison, New Jersey, Water Quality Laboratory, specifically Mr. Leo T. McCarthy and Mr. W. Librizzi are acknowledged with sincere thanks.

Commander Albert Stirling, U.S. Coast Guard, Washington, D.C., provided valuable assistance in reviewing the system design to establish compliance with Coast Guard Regulations.

The development, design, and demonstration testing was carried out by a team from the Thiokol Corporation, Wasatch Division. Key members of the team were T. J. O'Grady, Program Manager; P. Woolhiser, who served as Project Engineer during Phase I, and P. E. Lakomski, who served as Project Engineer for Phase II; L. W. Poulter, S. Moore, and Dr. D. P. Clark, Development Engineers; W. N. Christensen, Project Chemist; and O. W. Wilson, Biochemical Analyst.

SECTION I

CONCLUSIONS

1. As a result of the Pleasure Craft Waste Treatment System Development Program a practical, economical physical-chemical zero discharge waste treatment system has been demonstrated.

2. Because this system is a zero discharge system it fully complies with the no-discharge standard adopted by the EPA on 23 Jun 1972 and the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500).

3. With minor modifications, the pleasure craft waste treatment system will meet Coast Guard requirements for commercial vessels.

4. The program demonstrated that a device combining two unit operations (filtration and incineration) will effectively and safely remove and destroy sewage sludge.

SECTION II

RECOMMENDATIONS

1. Continue system development by modifying the system for a commercial vessel and conducting a demonstration program aboard such a vessel.

2. Submit the system for certification by the Coast Guard in accordance with proposed Certification Procedures and Design and Construction Requirements.

3. Increase system utilization by conducting a development program for treatment of other vessel wastes such as galley, bilge, and shower and washwater waste.

4. Apply the system to the treatment of waste in recreation areas, campgrounds, etc.

SECTION III

INTRODUCTION

STATEMENT OF PROBLEM

The Coast Guard Registry for Boats under the 1958 Federal Boating Act includes approximately 500,000 pleasure boats from 16 to 65 ft in length with over half in the 16 to 26 ft class and most of the remainder in the 26 to 40 ft class. Most of the 26 to 40 ft class boats are equipped with overnight accommodations for 4 to 10 people, and the number of these boats is increasing yearly. A new and very popular class of these boats is the cruising houseboat. These vessels normally operate in choice inland waters requiring strict control of discharge of waste. One of the national environmental goals is to prevent the discharge of pollutants into its navigable waters, and this goal was the prime motivation behind the work conducted under this program.

OBJECTIVES

The objectives of the pleasure craft waste treatment program were:

1. Conduct engineering research as necessary to refine a proposed treatment process into a system suitable for recreational vessel conditions.
2. Assemble a prototype system, and laboratory test the system to provide sufficient laboratory test data to demonstrate that the system would provide satisfactory treatment when installed aboard a recreational vessel.
3. Provide sufficient information to obtain a written opinion from the Coast Guard that the system will meet their safety requirements.
4. Install and demonstrate the prototype system onboard a houseboat.
5. Provide estimated retail costs plus installation and operating costs of the system.

TECHNICAL APPROACH AND SYSTEM DESCRIPTION

The basic approach proposed and chosen for treatment of sanitary waste aboard a pleasure craft was physical-chemical in nature. The program, as initially contracted, involved the development of a flow-thru treatment system to prevent the discharge of untreated waste. The process selected for development and demonstration involved the following physical-chemical processes:

1. Filtration of influent waste to remove coarse and suspended solids.

2. Incineration of the collected coarse and suspended solid material.

3. Chemical treatment of the collected filtrate to reduce BOD prior to discharge.

Steps 1 and 2 were accomplished in a single device developed by Thiokol. This "filter-incinerator" device combined these two unit operations into a compact, single component.

During the course of the development program, a no-discharge standard was adopted by the EPA. This standard was adopted on 23 Jun 1972 and resulted in a redirection of the program to develop a pleasure craft treatment system which would totally prevent the discharge of waste.

The system finally developed and demonstrated is shown in Figures 1 and 2. This system was installed on a houseboat and was in continuous use during the summer boating season of 1973. During that period, the system handled the waste of over 300 persons. Analysis of the recycle liquid showed a zero coliform bacteria count. The treated water was acceptable for reuse as flushwater.

Operation of the system is simple. Chlorinated water from the treatment tank is pumped to the toilet for flushing.

The system uses a standard camper-type low flush toilet. Toilet flushing is controlled by a pushbutton switch to actuate the flushwater pump. The flushwater and wastes accumulate in an 8 gal holding tank which is integral with the toilet. Generally, each evening, after a day of operation, the waste from the holding tank is pumped to the filter-incinerator. During the night, liquid drains through the filter and enters the treatment tank. In the morning, solids remaining on the filter are incinerated. High test hypochlorite (HTH) tablets are added to the treatment tank when the wastes are pumped to the filter-incinerator. The HTH oxidizes a majority of the wastes in the liquid and sanitizes it for reuse as a flush medium.

Once each week ash and noncombustible solids are vacuumed from the filter-incinerator for disposal with other trash which accumulates during regular use of the vessel.

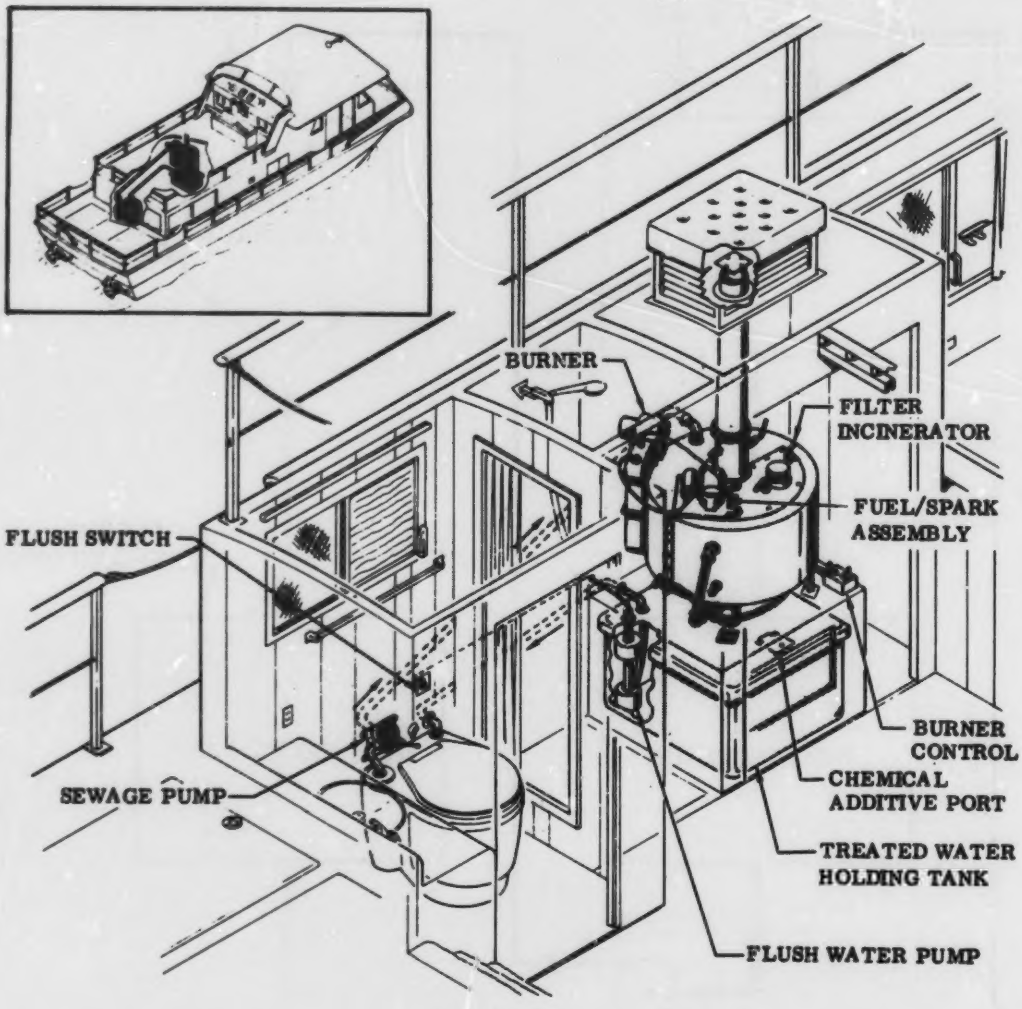

BURNER
FILTER INCINERATOR
FUEL/SPARK ASSEMBLY
FLUSH SWITCH
BURNER CONTROL
SEWAGE PUMP
CHEMICAL ADDITIVE PORT
TREATED WATER HOLDING TANK
FLUSH WATER PUMP

Figure 1. Small Pleasure Boat Waste Treatment System

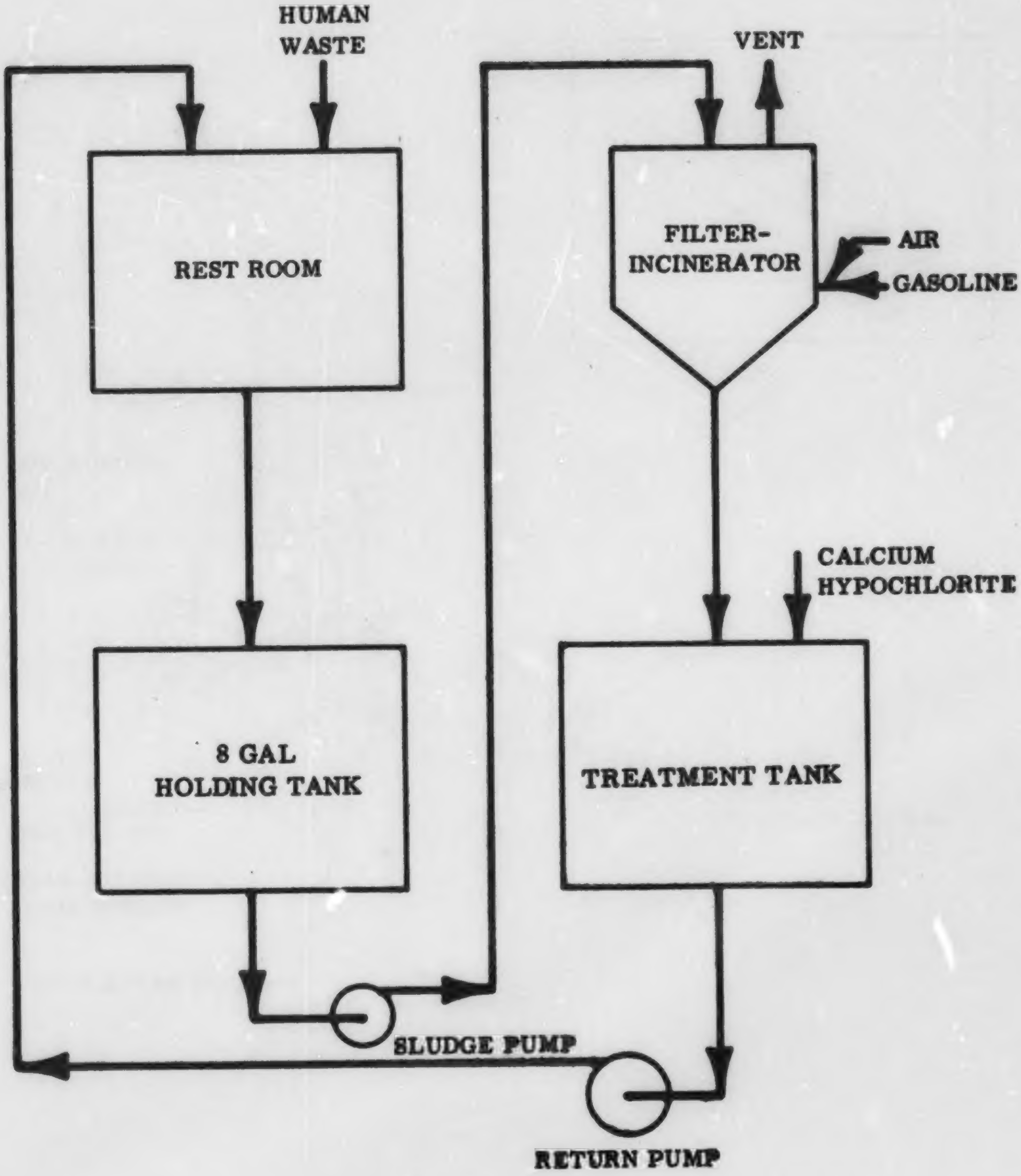

HUMAN WASTE
VENT
REST ROOM
FILTER-INCINERATOR
AIR
GASOLINE
CALCIUM HYPOCHLORITE
8 GAL HOLDING TANK
TREATMENT TANK
SLUDGE PUMP
RETURN PUMP

Figure 2. Houseboat Waste Treatment System Flow Diagram

SECTION IV

SYSTEM DEVELOPMENT

PROGRAM DESCRIPTION

The program comprised two distinct phases as follows:

Phase I - Development and Inplant Testing of a Prototype System

Phase II - Vessel Installation and Demonstration of the Prototype System

The Phase I program was initiated in July 1971. Original effort centered on development of a proposed packed bed filter-incinerator as the method for removal and disposal of suspended solids in the waste stream. The packed bed filter-incinerator had previously been demonstrated on a laboratory scale basis. Initial testing with a "scale-up" packed bed filter-incinerator revealed a problem in the form of excessive incineration time. The time required to raise the temperature of the packed filter bed to a level which would incinerate the collected sludge was several hours, an unacceptable time for a watercraft system. As a result, Thiokol requested a 90 day Phase I schedule extension on 22 Oct 1971 to permit incorporation of an advanced filter-incinerator design into the EPA program. This advanced filter-incinerator design was the result of Thiokol company-sponsored research on unique lightweight, low mass, high-temperature-resistant filter materials.

Program effort was reinitiated in February 1972, using a fabric cartridge filter element. The program was subsequently redirected on 17 Aug 1972 as a result of the EPA zero discharge standards which were published in the Federal Register on 23 Jun 1973. The redirection involved redesign of the system to "close-the-loop" converting the flow-thru system design to an effluent recycle mode conforming to the zero discharge standard.

The system was revised to investigate the zero discharge concept by adding PEPCON cells to generate hypochlorite and thus eliminating a majority of the chemical addition used previously. The subsequent program redirection with emphasis on a zero discharge system rather than a flow-thru discharge system resulted in reduced testing of the flow-thru system when the program was resumed. A 3 week demonstration test of the zero discharge system was conducted as part of the expanded program.

The Phase II, Vessel Installation and System Demonstration, effort was initiated on 20 Oct 1973. The program comprised fabrication and laboratory evaluation of the prototype vessel system, installation and checkout of the system aboard a Thiokol-provided 35 ft Nautaline houseboat and the conduct of a demonstration program aboard the houseboat during the summer of 1973. The demonstration program on the houseboat was conducted at Bear Lake, Utah, over the period 13 Jun 1973 thru 14 Sep 1973. During this period, 1,150 uses of the system was experienced.

As a result of a Coast Guard review of the system design additional laboratory tests were conducted on the system filter-incinerator using diesel fuel instead of gasoline to fire the incinerator. Coast Guard regulations prohibit the use of gasoline aboard commercial vessels.

PHASE I - LABORATORY TEST PROGRAM

Design Objectives

At the beginning of the Phase I, a set of design objectives was established based on the EPA requirements contained in the RFP and the design requirements established by Thiokol in responding to the RFP. Table 1 lists the design objectives on which preliminary system sizing was based. The objectives were based on a survey of small boat manufacturers and considered the waste producing capabilities of boats equipped with toilets, washbasins, showers, and galleys as well as the electrical power availability aboard typical boats. The fuel requirements were established subject to Coast Guard approval.

Filter-Incinerator Development

Testing on the program was initiated using an existing Thiokol laboratory filter-incinerator. This incinerator was a scaled-up version of the basic laboratory glass column incinerator which had provided the test data included in the Thiokol proposal for the program. The incinerator was comprised of an internal and external mild steel shell separated by an insulation barrier with the filter media assembled inside the inner metal shell as shown schematically on Figure 3.

Figure 4 provides a more detailed schematic of the system test configuration. Table 2 defines the makeup of the mixed media filter bed which was tested. Bed dimensions were 10 in. diameter by 16-1/2 in. high. All six of the tests initially conducted are summarized in Table 3. Heat for incineration was provided by a high pressure oil burner manufactured by Thermal Research and Engineering Corporation.

The mixed media filter bed had several operational problems that caused it to be unsuitable for use on a pleasure craft. The major problems were: (1) extended

TABLE 1

DESIGN OBJECTIVES

	EPA Requirement	Thiokol Goal
Influent Characteristics		
Suspended Solids (mg/l)	Not specified	500
BOD (mg/l)	Not specified	500
pH	Not specified	6.7 to 8.4
System Capability (Hydraulic Load)		
Total Capacity (gal /day)	Not specified	25
Peak Capacity (gal /day)	Not specified	33
Effluent Characteristics		
Suspended Solids (mg/l)	90% removal	50
BOD (mg/l)	90% removal	50
Coliform (mpn)	240/100 ml	100/100 ml
Physical		
Weight	Not specified	Minimum
Envelope	Not specified	Not to exceed 3 x 3 x 5 ft
Environmental		
Maximum Temp (° F)	Not specified	140
Minimum Temp (° F)	Not specified	28
Electrical Power	Not specified	12 to 36 vdc, 1 KW max. Adaptable for use with 110 vac when docked
Other Power	Not specified	Use of minimal quantities of fuel oil, butane, propane, or alcohol acceptable

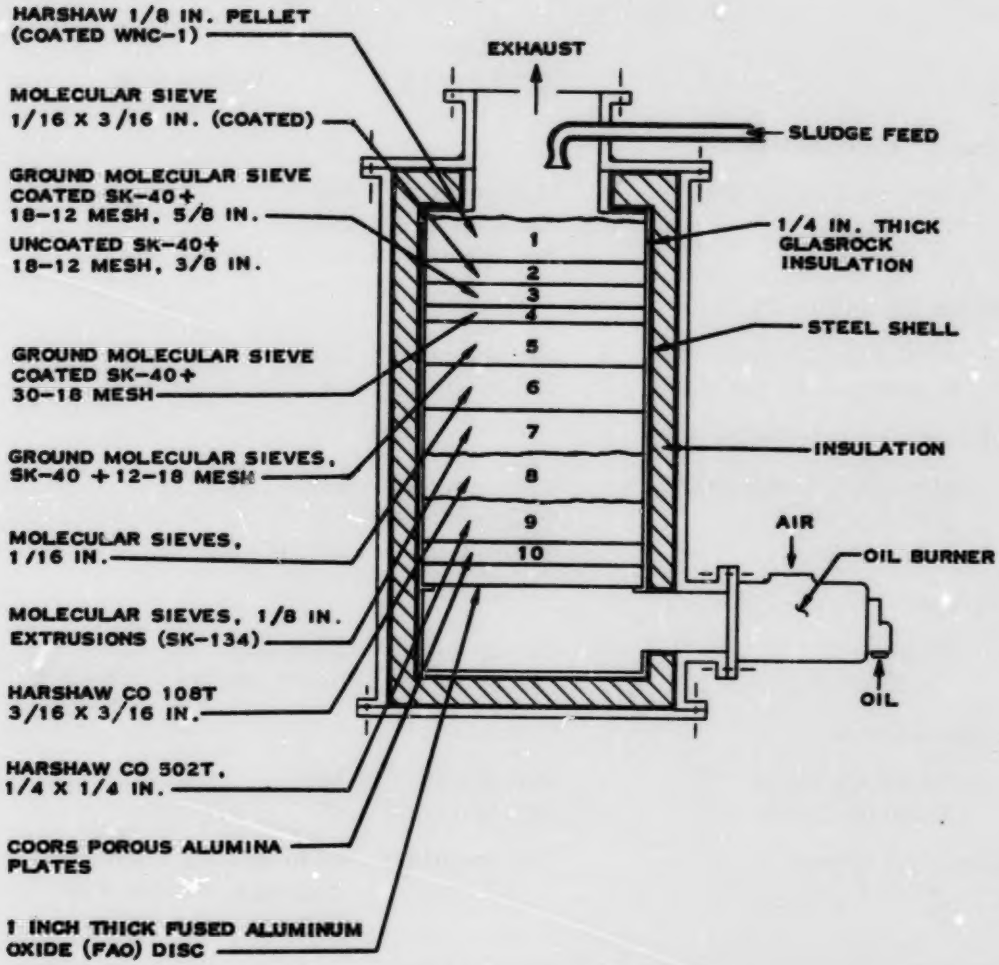
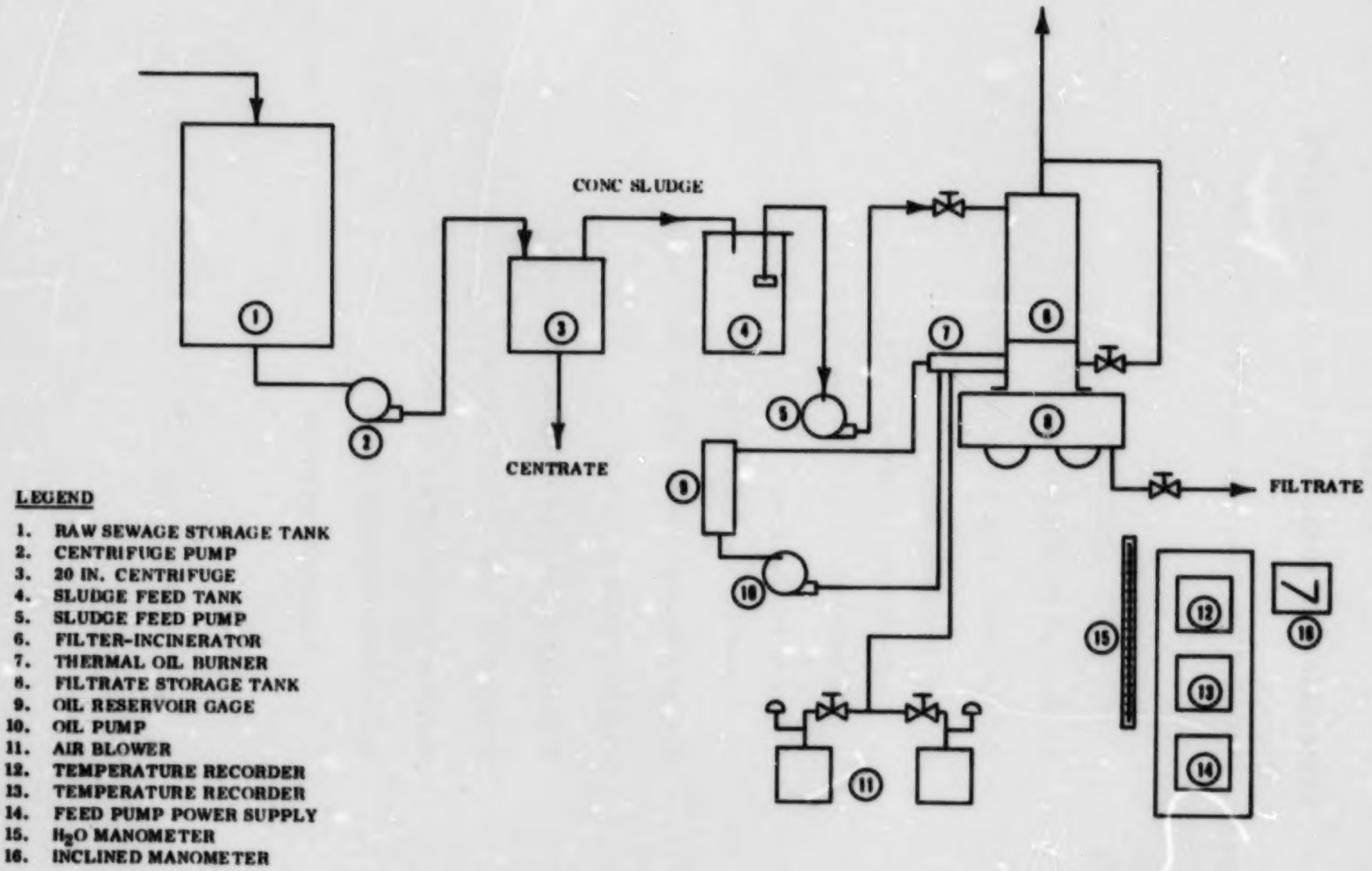

HARSHAW 1/8 IN. PELLET (COATED WNC-1)
MOLECULAR SIEVE 1/16 X 3/16 IN. (COATED)
GROUND MOLECULAR SIEVE COATED SK-40+ 18-12 MESH, 5/8 IN.
UNCOATED SK-40+ 18-12 MESH, 3/8 IN.
GROUND MOLECULAR SIEVE COATED SK-40+ 30-18 MESH
GROUND MOLECULAR SIEVES, SK-40 +12-18 MESH
MOLECULAR SIEVES, 1/16 IN.
MOLECULAR SIEVES, 1/8 IN. EXTRUSIONS (SK-134)
HARSHAW CO 108T 3/16 X 3/16 IN.
HARSHAW CO 502T, 1/4 X 1/4 IN.
COORS POROUS ALUMINA PLATES
1 INCH THICK FUSED ALUMINUM OXIDE (FAO) DISC
EXHAUST
SLUDGE FEED
1/4 IN. THICK GLASROCK INSULATION
STEEL SHELL
INSULATION
AIR
OIL BURNER
OIL
1
2
3
4
5
6
7
8
9
10

Figure 3. Filter-Incinerator Design (Packed Bed)


CONC SLUDGE
CENTRATE
FILTRATE
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

LEGEND

1. RAW SEWAGE STORAGE TANK
2. CENTRIFUGE PUMP
3. 20 IN. CENTRIFUGE
4. SLUDGE FEED TANK
5. SLUDGE FEED PUMP
6. FILTER-INCINERATOR
7. THERMAL OIL BURNER
8. FILTRATE STORAGE TANK
9. OIL RESERVOIR GAGE
10. OIL PUMP
11. AIR BLOWER
12. TEMPERATURE RECORDER
13. TEMPERATURE RECORDER
14. FEED PUMP POWER SUPPLY
15. H_2O MANOMETER
16. INCLINED MANOMETER

Figure 4. Flow Diagram and Equipment for Filter-Incinerator Tests

TABLE 2

COMPOSITION OF 10 IN. DIAMETER FILTER COLUMN

Bed Support 1 In. Thick Fused Aluminum Oxide (FAO) Disc

Layer No.	Description	Height (in.)
1	Harshaw 1/8 in. pellet (coated WNC-1)	2
2	Molecular Sieve 1/16 x 3/16 in. (coated)	1
3	Ground Molecular Sieve Coated SK-40+18-12 mesh, 5/8 in. Uncoated SK-40+18-12 mesh, 3/8 in.	1
4	Ground Molecular Sieve Coated SK-40+30-18 mesh	3/4
5	Ground Molecular Sieves, SK-40+12-18 mesh	2
6	Molecular Sieves, 1/16 in.	2
7	Molecular Sieves, 1/8 in. extrusions (SK-134)	2
8	Harshaw CO 108T, 3/16 x 3/16 in.	2
9	Harshaw CO 502T, 1/4 x 1/4 in.	2
10	Coors Porous Alumina Plates	1
	Total Column Height	16-1/2

TABLE 3

10 IN. DIAMETER FILTER-INCINERATOR TESTING

	Filtration										Incineration					
Test	Date 1971	Bed Height (in.)	Bed Composition	Feed Volume (gal)	Type Feed	Feed Config	Avg Feed Rate (gpm)	Suspended Solids (mg/l) Feed	Suspended Solids (mg/l) Filtrate	Suspended Solids (mg/l) % Removal	Date 1971	Max Bed Temp (°F)	Time to Bed Temp Increase (hr)	Bed Pressure in H_2O	Time to Final Temp (hr)	Remarks
1	8-10	16-1/2	(a)	50	RS(b)	(c)	2-1/4	1,670	310	81.[illegible]	8-12	885	2	23-43	3-3/4	
2	8-17	16-1/2	(a)	500/50(d)	TS(e)	(c)	2.6	970	76	92	8-18	1,100	1-3/4	32-37	2-3/4	Filter effluent treated in catalyst column - final SS 7 mg/l.
3	9-14	2	(f)	30	TS	(c)	--	--	--	--	9-14 9-15	970	--	--	--	
4	9-16	2	(f)	20	TS	(c)	--	413	64	84.5	9-16	--	1/4	1/4	3/4	Gas analysis taken on stack.(g)
5	9-16	2	(f)	20	TS	(c)	--	448	297	33.8	9-16	1,080	1/4	1/4	3/4	Note: Clarified feed to filter. 132 mg/l SS solids retained on filter appeared to be washing through bed.
6	9-23	2	(h)	400/40(j)	TS(i)	(c)	--	--	80	--	9-24	900	1/6	0.5-1.6	3/4	

(a) Bed composition - 16-1/2 in. deep bed located as per Table 1.
(b) RS - Indicates raw sewage influent - no pretreatment.
(c) Feed configuration - subsurface draw off of stilled volume.
(d) 500 ga.. RS concentrated with 20 in. centrifuge to 50 gal.
(e) TS - indicates treated sewage at dosage of 1.2 lb HTH per 50 gal. (2,000 ppm OCl^-).
(f) Bed composition - 2 in. height 1/4 x 1/4 in. Harshaw pellets over 6 x 6 in. mesh screen support.
(g) Gas analysis of stack - O_2 - 16.9%; N_2 - 81.9%; CO - None; CO_2 - 3.4%.
(h) Bed composition - 2 in. of 1/4 x 1/4 in. pellets over FAO No. 24 - inch thick porous plate.
(i) TS - treated sewage 165 gm HTH (750 ppm hypochlorite).
(j) 400 gal. RS concentrated to 40 gal.

combustion times, (2) high pressure drop across the filter bed during combustion hence a high pressure burner system, and (3) the necessity to pretreat the waste to assure development of a filter mat on top of the filter bed. Use of a settling basin was also considered to preconcentrate the waste material prior to filtration. Regardless of the pretreatment methods considered, the major problem associated with the mixed media filter bed was excessive incineration time. This is illustrated in Figure 5 which provides profiles of bed temperature and pressure drop as a function of time. As can be observed, approximately 2 hr of burn time were required to raise the bed temperature to a level to initiate destruction of the collected solid material and water in the bed. These incineration times and the requirement for a high pressure burner system were considered incompatible with the requirements for a simple, low cost pleasure craft waste treatment system.

Improved Design

Specific filtration-incineration concepts which were evaluated comprised cloth and porous ceramic type materials as filter elements in a gasoline-fired, single element, test rig (Figure 6). Figure 7 is a photograph of the test setup. Tests of various materials and filter elements were conducted over a 3 month period. A detailed summary of the filter-incinerator tests conducted is presented in Appendix I. Table 4 summarizes the results of the tests.

The following conclusions in addition to those noted in Table 4 were derived from the data collected relative to the most promising filter element materials.

Refrasil Cloth--Refrasil is a 99+% pure amorphous silica in a continuous filament manufactured by Hitco Materials Division, Gardena, California. Refrasil was created for the aerospace industry, where large quantities are used as ablative compound reinforcement in rocket nozzles, combustion chambers, and reentry shields. This material, which is also used as a thermal insulation and a flame barrier in aircraft construction, was first evaluated at Thiokol as a filter element in sheet form. The material was wrapped around a support tube and retained by a wire mesh screen and clamps as shown on Figure 8. Two types of Refrasil were evaluated: plain (C100-48), and "Irish" (C1554-48). The difference between the two is that "Irish" Refrasil is impregnated with chromium oxide. As shown by the test data on Table 4, both forms of Refrasil produced satisfactory filtrates and throughputs, and both withstood the incineration temperature. Subsequent tests with Refrasil were conducted with B2-1/2 Refrasil braid, a braided seamless form of the C100 material, which is provided in long tubes. This braided material was assembled over stainless steel perforated plate support tubes in one and two layers for testing. Again satisfactory test results were obtained, and one element was subjected to 40 consecutive filtration-incineration cycles (Runs GF-83 thru GF-122). Figure 9 shows the element prior to the 40 cycle tests, and Figure 10 is the same element after the test. No material degradation was observed. Based on test results in the single element test rig, the Refrasil braid was selected as the prime candidate material for the multiple element demonstration test rig

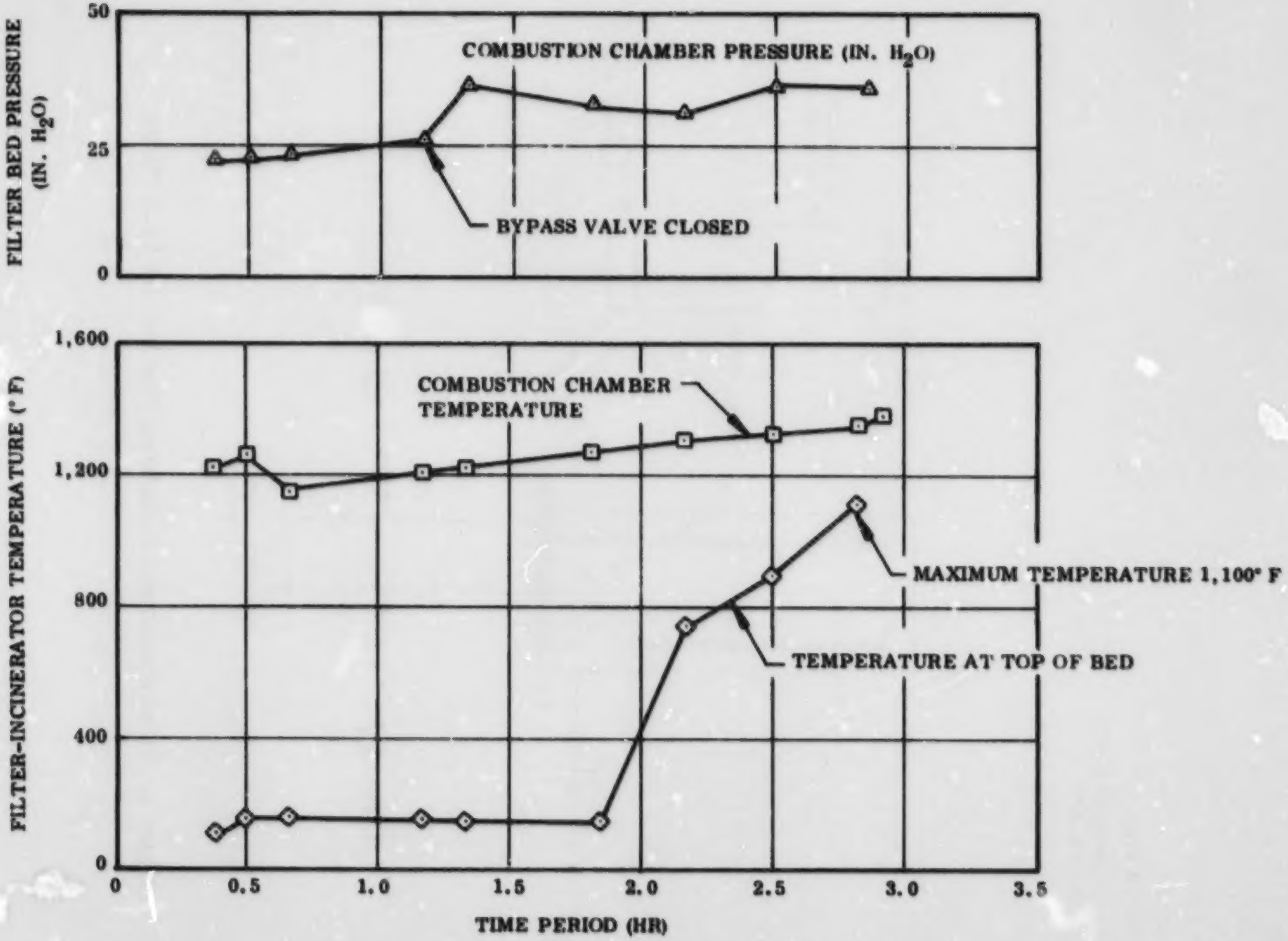


Figure 5. Profile of Filter-Incinerator Temperature and Bed Pressure (Test 2)

TEST CYCLE:

1. FILTER
2. INCINERATE
3. BACKWASH WITH WATER TO REMOVE ASH

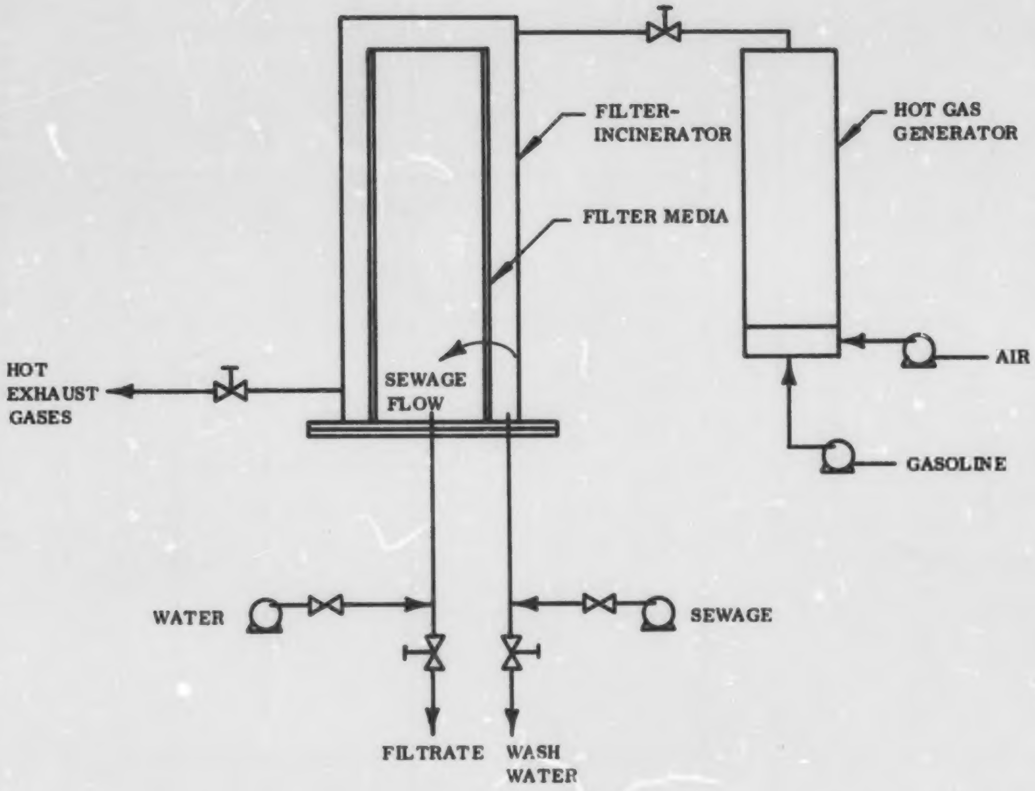

FILTER-INCINERATOR
HOT GAS GENERATOR
FILTER MEDIA
AIR
HOT EXHAUST GASES
SEWAGE FLOW
GASOLINE
WATER
SEWAGE
FILTRATE
WASH WATER

Figure 6. Filter-Incinerator Cylindrical Test Unit for Cloth Media

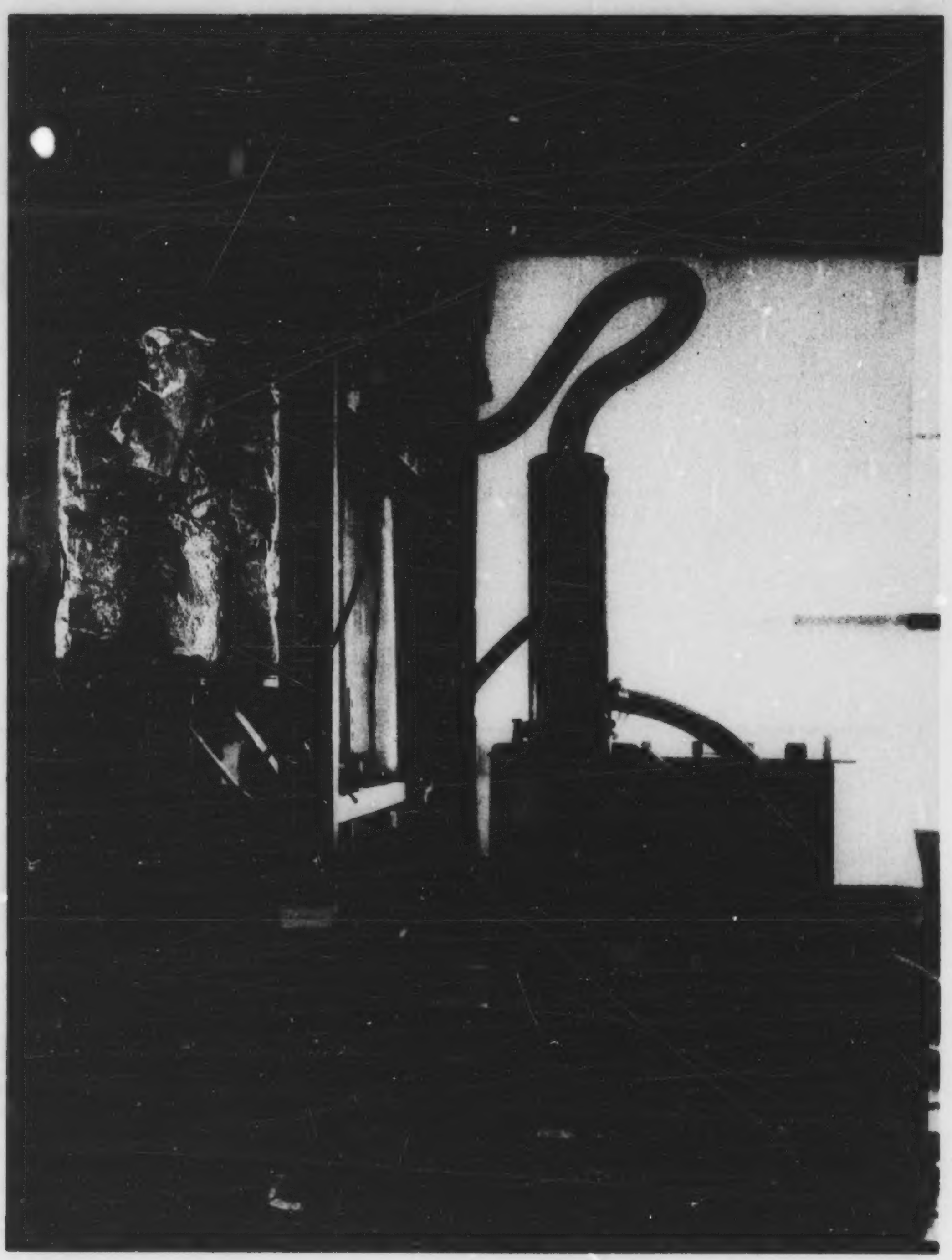


Figure 7.   Glass Cloth Test Rig

TABLE 4

FILTER MATERIAL EVALUATION

Supplier	Material	Test Results	Test
Hitco	Refrasil cloth, C1554-48 "Irish," tested in 1-ply	Also tested (filtration tests) C100-96, C100-28, C1554-96 and C1554-28	GF-1 GF-2 GF-44
	Refrasil cloth C100-48 "Plain," tested in 1- and 2-ply	Satisfactory filtration obtained for all weights of cloth, Refrasil tube, and Refrasil batt.	GF-3 through GF-13 GF-59
	Refrasil Cloth C1554-48 "Irish," tested in 2-ply		GF-14 through GF-25
	Refrasil batt (Fabbat) B-1570		GF-46
	Refrasil cloth C1554-48 Tested in 3-ply		GF-47 through GF-49
	Refrasil tube, tested in 1- and 2-ply, B 2-1/2	GF-51 thru 57 with same tube 1-ply, GF-60 thru 67 with same tube, 2-ply. Incineration at 1,150° F for all cycles	GF-51 through GF-57 GF-60 through GF-67
	Refrasil tube, B 2-1/2, 2-ply with Inconel support	40 cycle (filtration-incineration) test using HTH pretreated sewage. Incineration was at 1,050° F for all cycles. Element in excellent condition after 40th test	GF-83 through GF-122
		Attack by sea water observed when filtration was followed by incineration at 1,150° F. Lab tests have indicated material is satisfactory if temperature is reduced to 1,050° F or less	
Raybestos-Manhattan	High temperature asbestos cloth "Novatex" L-70-791 16 oz 1-ply	16 oz 1-ply produced unsatisfactory filtrate; 24 oz 1-ply marginal filtrate; 24 oz 2-ply satisfactory filtrate. Must be incinerated at less than 1,050° F	GF-26 through GF-28
	L-70-652 24 oz 1-ply	Lab tests indicate material is satisfactory for sea water service at 1,050° F. Multiple cycle filter-incinerator tests with 2-ply cloth were conducted successfully using 3% salted sewage	GF-29 through GF-33
	L-70-652 24 oz 2-ply		GF-68 through GF-79
	L-70-652, 24 oz 2-ply	40 cycle filtration-incineration test. First 7 cycles with HTH treated sewage, remaining 33 with 3% salted sewage. Element in excellent condition after 40th cycle. Incineration at 1,050° F all cycles	GF-126 through GF-165
Thermal American Fused Quartz Co.	Quartz cloth Style 570 19.5 oz/sq yd 0.027 in. thick, 5H satin weave	Tested in 1- and 2-ply. Satisfactory filtration with 2-ply. Satisfactory incineration in fresh water sewage. Unsatisfactory after two incinerations in sea water sewage. No plans to further test.	GF-35 through GF-42
	Quartz cloth Style 581 8.4 oz/sq yd 0.011 in. thick, 8H satin weave	Not tested - weave too coarse	

TABLE 4 (Cont)

FILTER MATERIAL EVALUATION

Supplier	Material	Test Results	Test
Electro Refractories and Abrasives	Fused aluminum oxide porous plates		
	4 in. dia x 7/16 in. thick FAO No. 36	Marginal filtration efficiency. Thermal cracking experienced during incineration with both plates and cylinders. No plans to conduct further tests	PPF-2 through PPF-5 PPF-10 through PPF-11
	4 in. dia x 1 in. thick FAO No. 24		PPF-6 through PPF-9
	8 in. dia x 1 in. thick FAO No. 12		OF-1 through OF-4
	12 in. sq x 1 in. thick V - groove, FAO No. 54		OF-5 and OF-6
	12 in. sq x 1 in. thick BiPorous FAO No. 12-36		OF-7 and OF-8
	8 in. dia x 1 in. thick FAO No. 12		OF-9 and OF-10
	Fused aluminum oxide cylinders		
	3 in. OD x 2 in. ID x 12 in. L FAO No. 80		PPF-12, 12 PPF-22, 23
	3 in. OD x 2 in. ID x 12 in. L FAO No. 54		PPF-15 through PPF-21
Electro Refractories and Abrasives	4 in. dia x 1/2 in. thick SiC disc, "fine" porosity	Satisfactory filtration - no incineration test conducted	PPF-1
	8 in. dia x 1 in. thick SiC No. 12	Quench test conducted at temperatures up to 550°F. Salt water quench - no cracking experienced Lab tests in sea water at 1,150 °F shows attack of binder	
	3 in. OD x 2 in. ID x 12 in. L SiC No. 80	Tested for one filter incineration cycle - good throughput and filtrate	GF-82
	3 in. OD x 2 in. ID x 12 in. L SiC No. 54	Tested for 2 filter-incineration cycles. Good throughput using raw sewage. Satisfactory filtrate	GF-80 GF-81
Fluid Dynamics, Inc	X-6 wire tube 2-3/4 in. OD x 10 in. L, 15 fibrous stainless steel	Filtrate data not conclusive. Satisfactory incineration	GF-50 and GF-58
Union Carbide	Zirconia cloth (Zirconium dioxide)	Lab data indicate this material may not degrade at 1,100°F in sea water. Material not as strong as Refrasil. Larger sample tested. Poor filtration - no plans to evaluate further	GF-125

TABLE 4 (Cont)

FILTER MATERIAL EVALUATION

Supplier	Material	Test Results	Test
Brunswick Corporation	Metallic cloth Brunsmet 304 SS fiber	Poor filtrate resulted during filtration test. No further tests	GF-124
	Brunspore metal Fiber media	Same as Fluid Dynamics material - Fluid Dynamics is a Division of Brunswick	
	Sintered stainless steel beads Sintered cylinder	Low throughput - not incinerated, no further tests	GF-34
GAF Corporation	5 micron polypropylene bag (non-reusable) 25 micron polypropylene bag	Satisfactory filtration, bag and collected solids successfully incinerated. No further tests due to nonreusability of bag	None
Bendix Filter Division	Poroplate 1 in. dia SS 5 layer wire mesh, 100μ	Screening tests were satisfactory. Element was purchased as a backup	None
Mott Metallurgical Corp	Sintered metal filters, approx 1 in. x 2 in. samples varying in porosity from 1/2 micron to 100 microns.	Screening tests were satisfactory. Element was purchased as a backup	
Refractory Products Co	WRP-X-AQ felt (Al_2O_3 - SiO_2 fibrous insulator)	Filter failed	GF-123

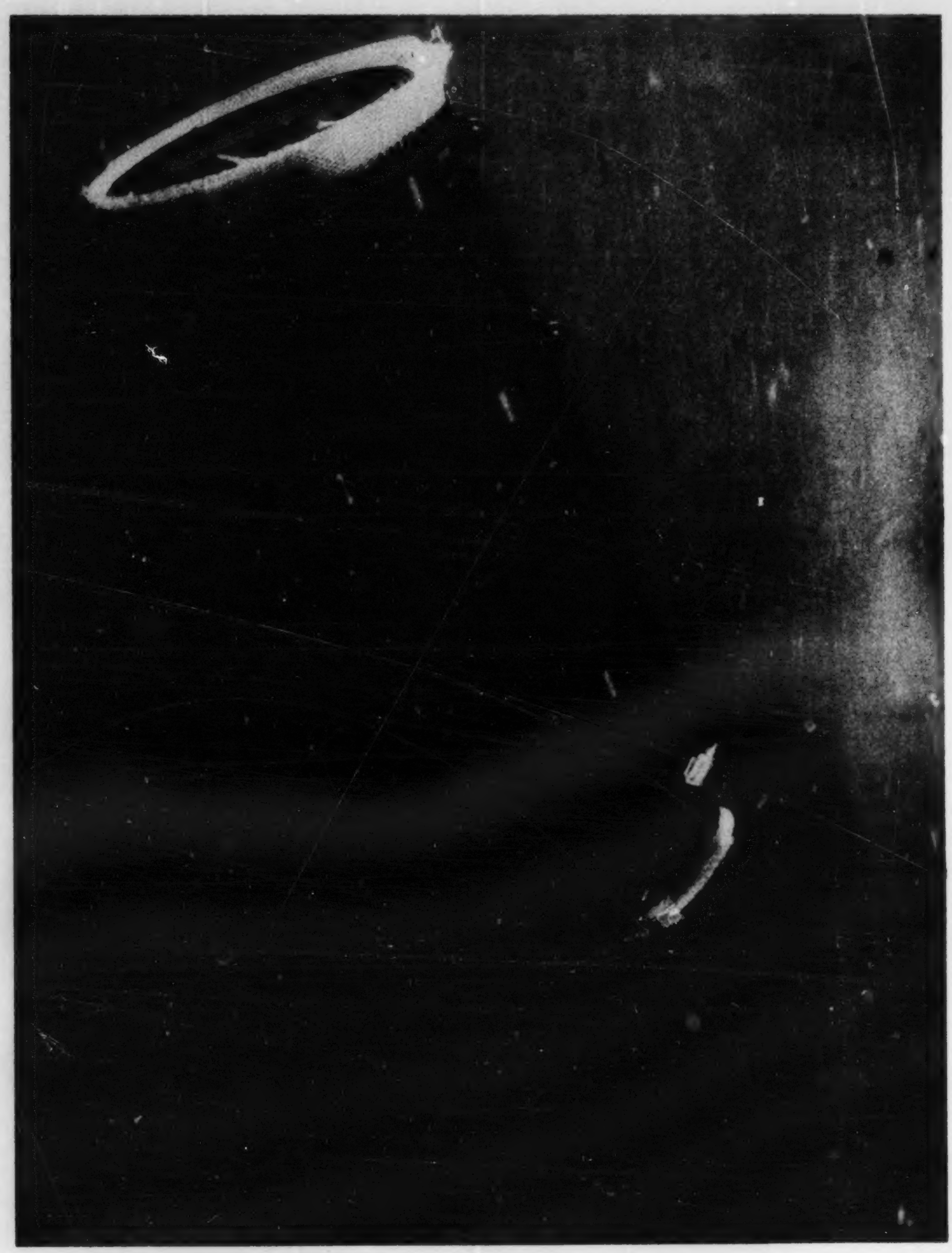


Figure 8. Glass Cloth Filter

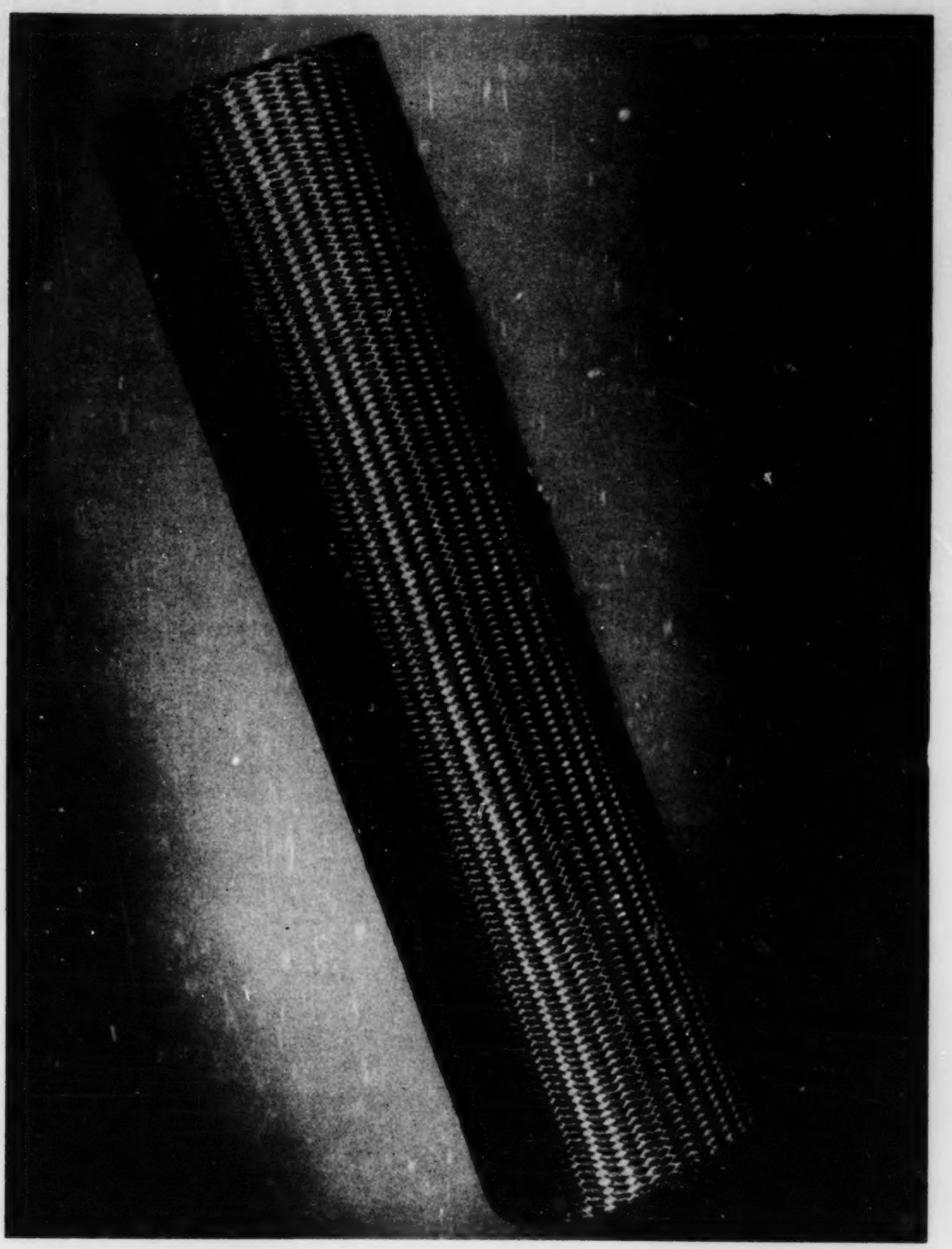


Figure 9. Refrasil Filter, Before Test

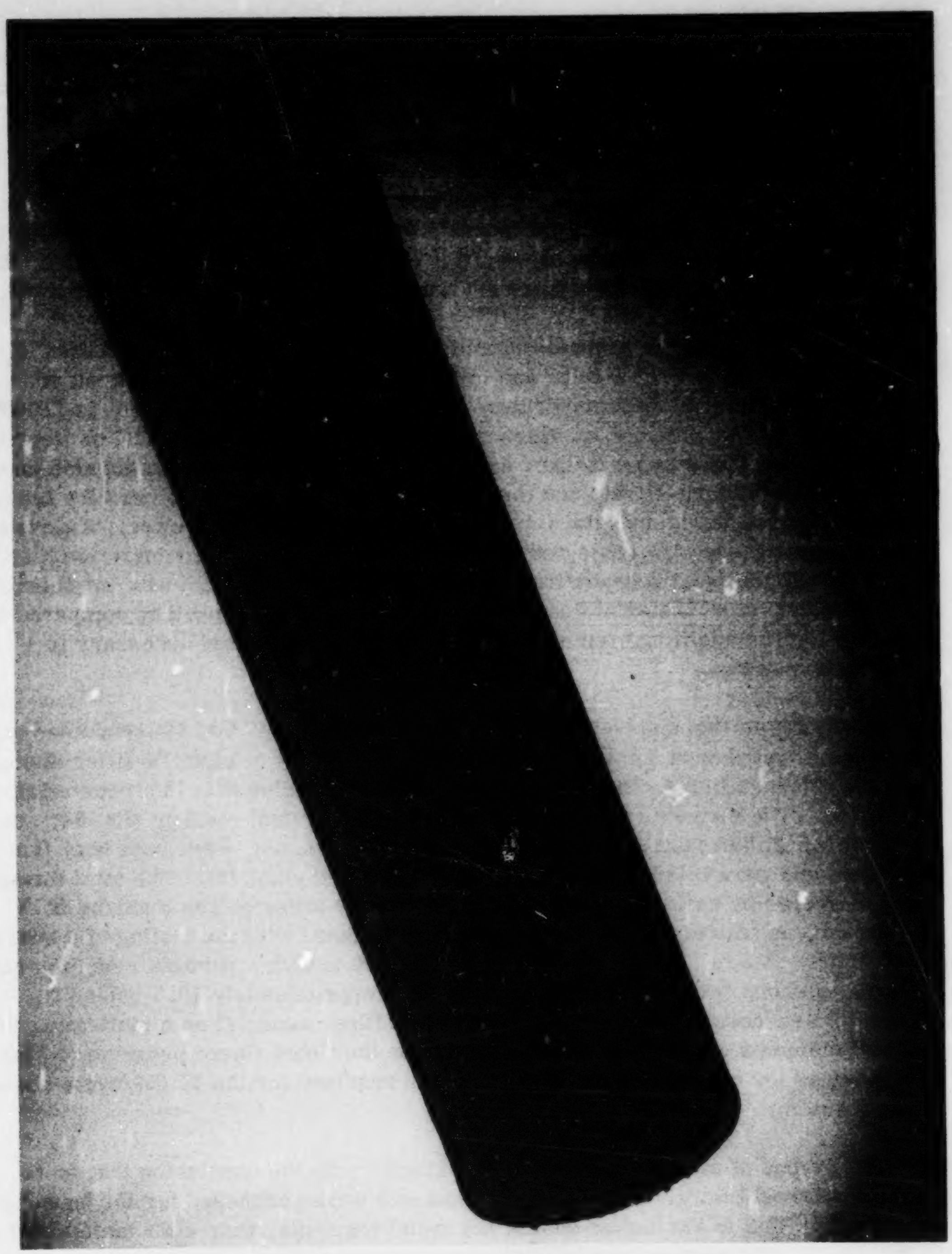


Figure 10. Refrasil Filter, After 40 Cycle Test

because it exhibited the best temperature resistance of all materials evaluated under all operating conditions. Refrasil does not melt or vaporize until temperatures exceed 3,100° F, and will function continuously with little or no change in properties. In the filter-incinerator, temperatures are controlled to 1,100° F maximum, thus providing an adequate temperature margin.

Extensive testing was conducted on the Coast Guard program to determine if salt (both NaCl and sea salt) had a measurable effect on Refrasil. Runs GF-60 thru GF-67 (Appendix I) show typical results. No adverse effects were detected, thus providing additional data in a more severe environment on the Refrasil material.

Novatex--Novatex is an asbestos textile developed by Raybestos-Manhattan, available in a variety of weaves and in three weights, 8, 16, and 24 oz/sq yd. Its maximum operational temperature, as noted by the manufacturer, is 1,000°F. The material was obtained by Thiokol in sheet form in both 16 and 24 oz weights and evaluated in the same manner as the Refrasil cloth. The Novatex also produced a satisfactory filtrate and throughput and withstood the incineration temperature as long as the temperature was maintained at 1,050°F or lower. A Novatex filter element was also subjected to 40 consecutive filtration-incineration test cycles. No material degradation was observed. This material was not selected as the prime cloth material due to its lower temperature capability compared to Refrasil. The additional temperature margin was considered necessary in a production design.

Metallic Filter Elements--Initial screening tests (GF-34, 50, 58) conducted on the Coast Guard program to determine the applicability of metallic filter elements to the Thiokol filter-incinerator system placed these elements in a poor relative position. The elements tested, a sintered stainless steel element (GF-34), and a 15 micron Fluid Dynamics woven element (GF-50 and 58), were both very fine grained and were blinded rapidly by the sewage feed material. The total throughput delivered by each of these elements was of the order of 2 to 3 gal/sq ft. However, an entirely different picture was presented with the testing of a coarser material. A 1 in. diameter Bendix Poroplate disc with a particle retention rating of 100 microns delivered an equivalent flow of approximately 13.5 gal/sq ft. With this success and the desire for a backup filter material as a motivating force, metal elements were evaluated extensively on the Coast Guard program, which had a need for much higher throughputs than required for the 15 gal/cycle houseboat system.

Several types of metal elements were evaluated with the conclusion that metal elements would work. Several metal elements were purchased for the houseboat program. Due to the higher cost of the metal elements, they were maintained as "backup." The need for use of the backup elements did not arise.

Burner Assembly--An important component of the filter-incinerator is the burner. The laboratory studies indicated 80 to 100 SCFM of 1,100°F air was needed for incineration. Numerous manufacturers were contacted to locate burner equipment to meet these requirements; however, the combination of relatively high temperatures and low air flow rates eliminated most of the available equipment. The Model 8304A "Southwind" heater made by Stewart-Warner was found to be suitable for the filter-incinerator.

The Southwind heater is used on numerous motor vehicles as an engine preheater in one form and as a passenger compartment space heater in another form. The burner uses gasoline as a fuel and the hundreds of units presently in service attest to the safety and reliability of this type of unit.

The use of gasoline as a fuel for a pleasure craft waste treatment system is very convenient, since most boats have gasoline powered engines. Some safety precautions must be taken when using gasoline, such as venting of vapors and flame assurance devices. These precautions have been included in the incineration equipment. Discussions with the Coast Guard have indicated that the use of propane or other low boiling point gaseous fuels is not desirable (although propane fueled stoves are in common use on pleasure craft). Although gasoline could not be approved for use on commercial vessels, no serious objections were raised to its use on pleasure craft (which are not governed by U.S.C.G. regulations). In view of the reliability, safety in motor vehicular applications, and accessibility of gasoline, it was decided to fuel the incinerator with gasoline, and consider the use of a less volatile fuel (such as fuel oil) at a later date based on a Coast Guard review of a prototype system design. Use of gasoline eliminated the need for a separate fuel tank for the waste treatment system installed aboard a pleasure craft.

Secondary Treatment

Secondary treatment is that portion of the waste treatment system that reduces the BOD and suspended solids of the filtrate issuing from the filter-incinerator. The Thiokol approach to secondary treatment for the pleasure craft system was to oxidize the dissolved organic material in the filtrate using a strong oxidizing agent, hypochlorite. Two methods of providing hypochlorite were considered; chemically adding the hypochlorite in the form of sodium or calcium hypochlorite or onsite generation of the hypochlorite by an electrolytic process from a NaCl solution. Both methods were evaluated in the development program. All of the initial laboratory tests were conducted by adding hypochlorite in the form of sodium or calcium hypochlorite. Since reaction of the hypochlorite with the dissolved organic material is a time-dependent process these early tests also involved the use of a chemical catalyst developed by Thiokol to accelerate the oxidation process.

A measure of effectiveness of the catalyst is the rate at which the catalyst will lower the concentration of available chlorine in an aqueous solution. Figure 11 depicts a laboratory test in which solutions containing about 2,000 ppm Cl_2 were placed in containers in contact with various amounts of two Thiokol-developed catalysts (WNC-1 and CCC-6). The catalyst was placed on the bottom of the container and there was no agitation of the liquid during the test. The CCC-6 catalyst showed higher initial activity, and in 24 hr the chlorine level was reduced to 50 ppm. Later tests indicated the CCC-6 catalyst loses activity and, at ambient temperature, could have a performance very similar to WNC-1 catalyst after 1 to 2 weeks of service. Previous tests at Thiokol showed that catalyst activity could be increased by increasing temperature, but this approach was not considered for the pleasure boat system due to the limited power available on such a vessel.

Laboratory secondary treatment tests involved evaluation of various treatment levels and catalyst amounts. Tests were conducted using 1 qt samples with the catalyst deposited at the bottom of the quart jar. Figure 12 is typical of the results obtained. Reduction in BOD was the primary criteria for judging test results. These tests with the varying amounts of catalyst gave the following results:

1. With a feed BOD of 300-400 ppm, 1,000 ppm Cl_2 was too low a treatment level; 2,000 ppm seemed optimum.

2. 100 gm of catalyst per 500 ml of solution appeared optimum.

3. The catalyst had the definite effect of lowering BOD and free chlorine levels in a hypochlorite treated solution.

Later tests used 3 gal tanks, and the effects of catalyst placement and circulation of solution through a catalyst column were studied. The catalyst was either deposited in the bottom of the 3 gal tank, suspended in porous nylon bags in the tank, or located in a column adjacent to the tank. In the latter case, a pump was used to circulate the liquid through the catalyst column. Results are shown below. Dispersed catalyst generally gave the lowest effluent BOD; circulation did not appear beneficial, although circulation did cause the chlorine level to drop faster than in other schemes. Indications were that circulation causes increased free chlorine destruction, but did not appreciably improve BOD reduction.

		WT WNC-1 (GRAMS)			WT CCC-6 (GRAMS)		
		50	100	150	50	100	150
NaOCl CONC AT (PPM)	0 HR	1,800	1,800	1,800	1,950	1,950	1,950
	5 HR	1,125	850	725	950	550	650
	24 HR	410	270	210	130	80	50

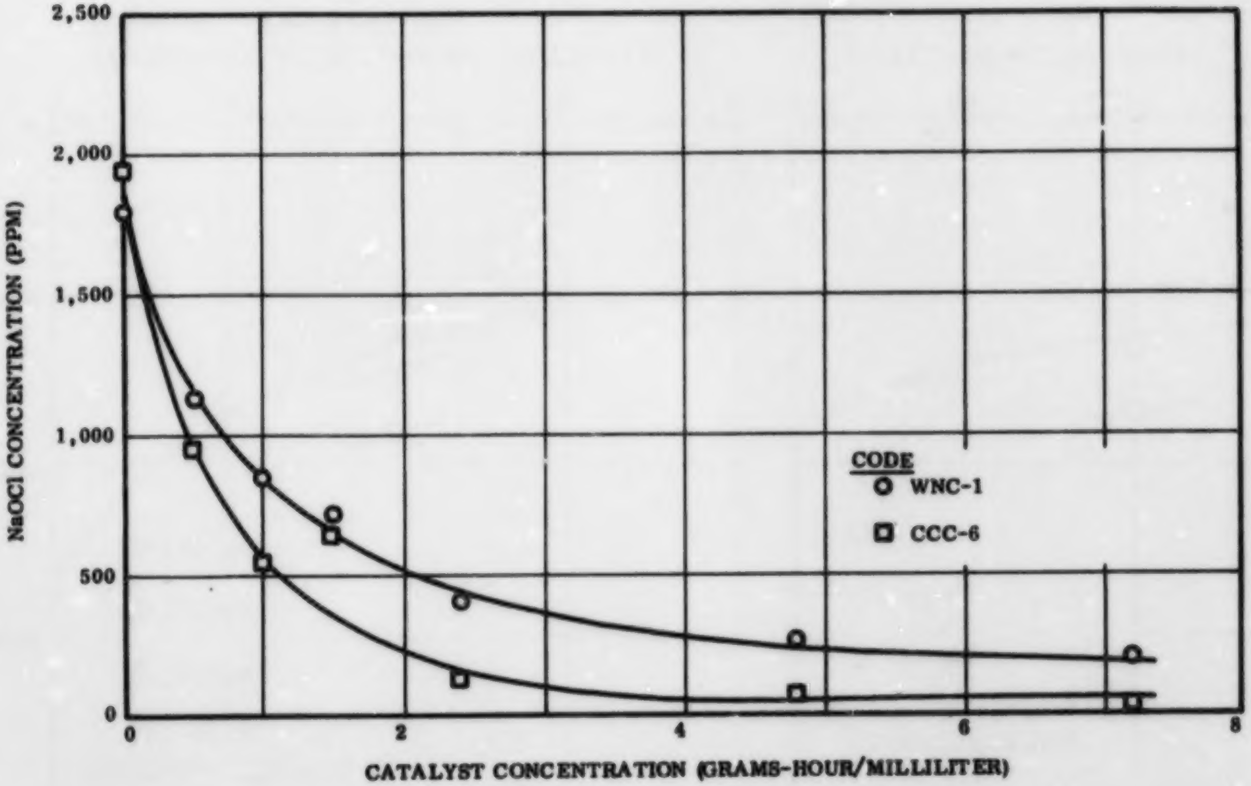


Figure 11. Catalyst Calibration Data - Static Reactor (65°-70° F)

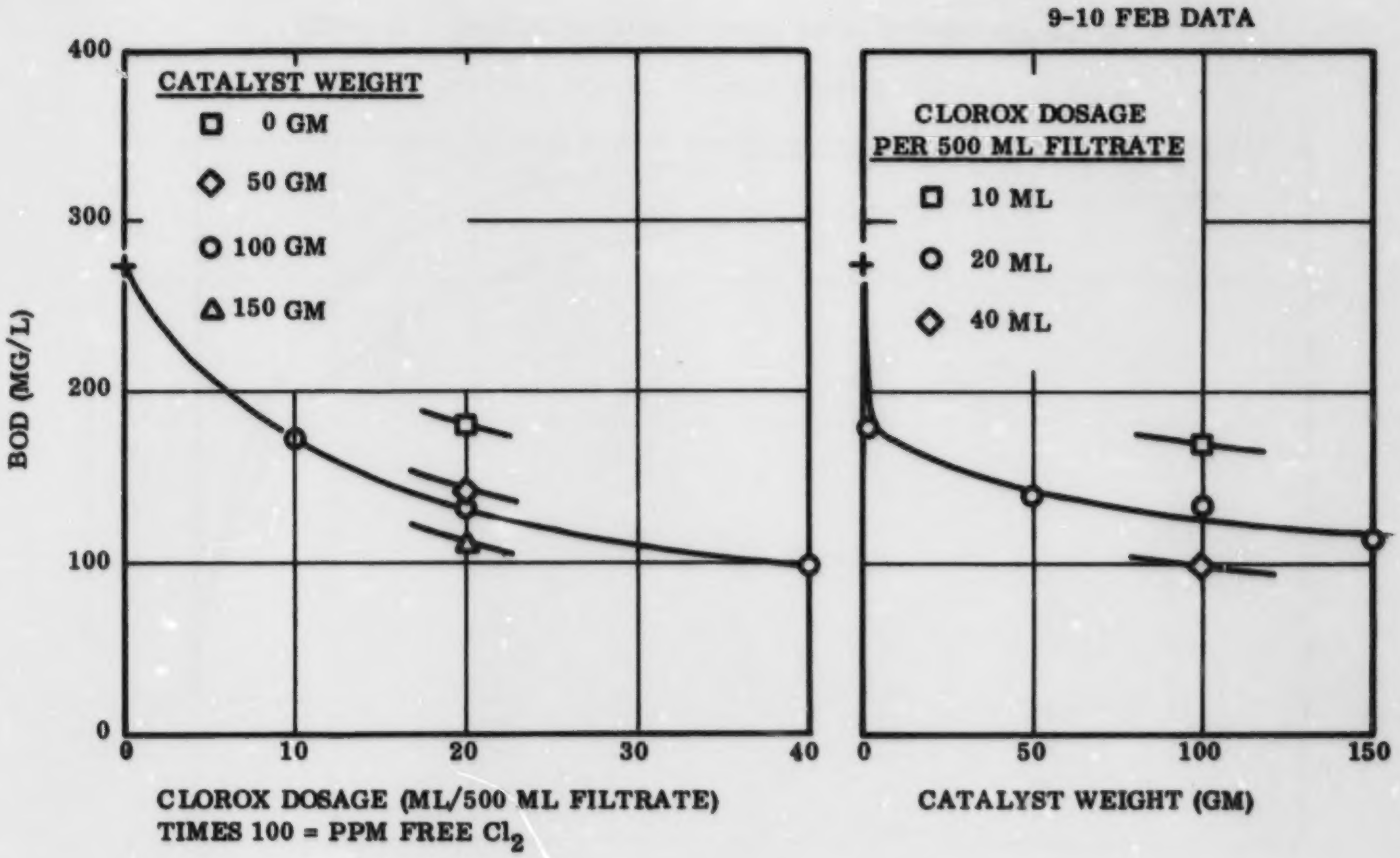


Figure 12. Catalytic BOD Reduction, Ambient Temperature, Static Reactor (WNC-1 Catalyst)

PILOT CATALYST TEST RESULTS
(BOD'S IN PPM)

Feed	Tank 1	Tank 2	Tank 3
236	57	51	58
370	58	57	49
279	70	68	45

Tank 1 had catalyst at bottom of solution.

Tank 2 utilized circulation through a catalyst column.

Tank 3 had cylinders of catalyst suspended in the solution.

All tests utilized WNC-1 catalyst.

Total contact time 22-25 hr.

One additional phase of the laboratory secondary treatment investigation was a test to determine the effectiveness of catalyst in reducing BOD at room temperature. Figures 13 and 14 depict a test where three 3 gal containers were filled with a sewage solution containing 215 ppm BOD, 124 ppm suspended solids, and 950 ppm Cl_2. One container had catalyst present the entire 22 hr test period, one container had no catalyst the entire period, and the remaining container had catalyst added after 9 hr of chlorine contact time.

Testing on other systems has shown that higher treatment temperatures will speed the reduction of BOD in the presence of catalyst. However, Figure 13 shows no discernible effect of catalyst on BOD or suspended solids at ambient conditions. Figure 14 does show that the use of catalyst will remove free available chlorine. Further confirming tests with catalyst were conducted during the demonstration program.

During the laboratory tests it was noted that addition of an alkaline hypochlorite to sewage produced a white precipitate. The secondary treatment section was designed to include a solids settling section to prevent discharge of this material.

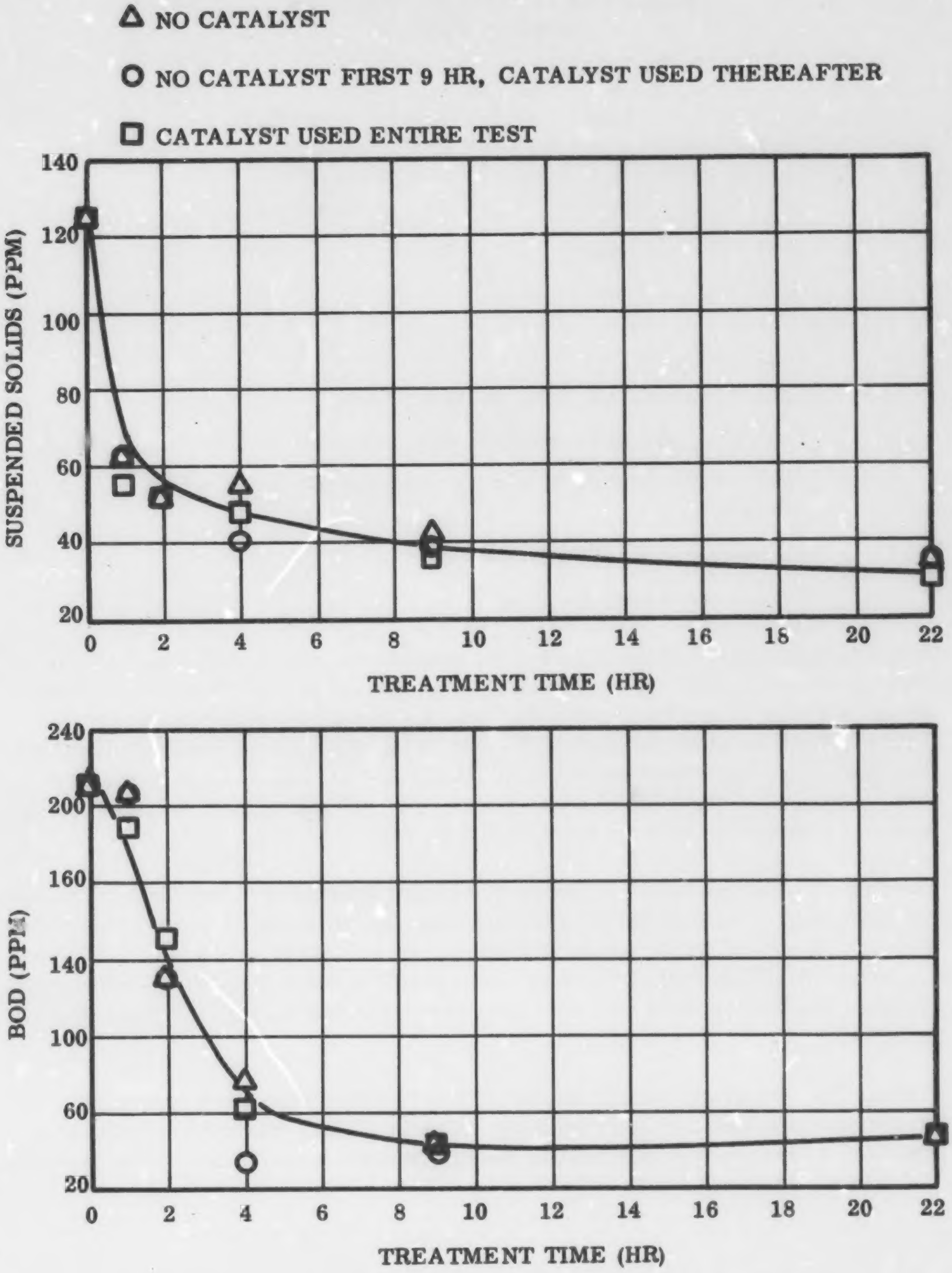


Figure 13. Effect of WNC-1 Catalyst on BOD and SS Removal

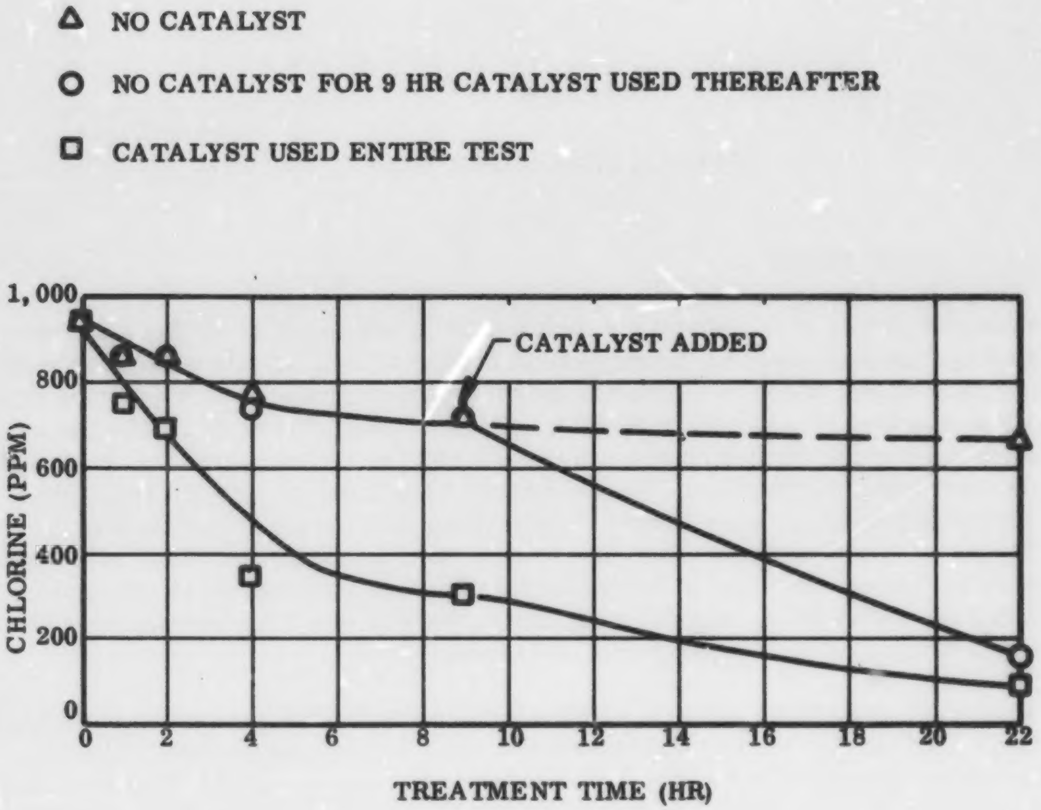


Figure 14. Effect of WNC-1 Catalyst on Cl_2 Removal

SECTION V

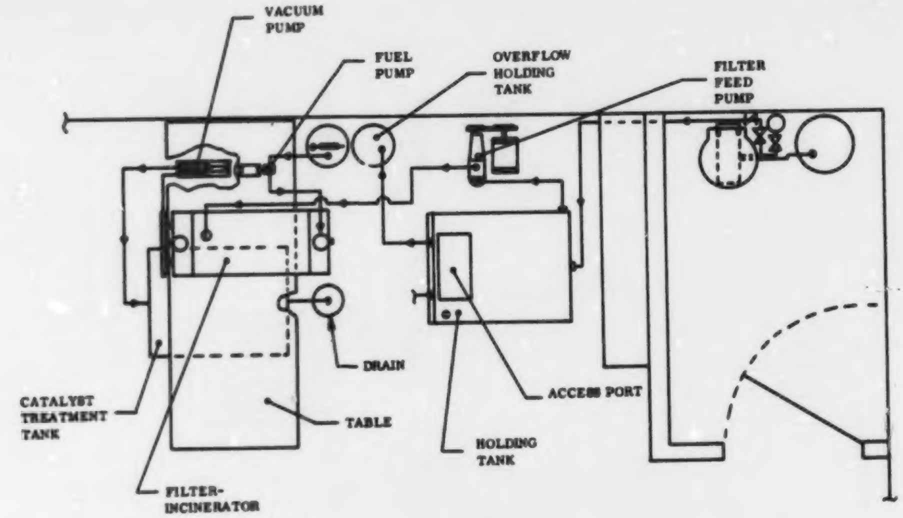
SYSTEM DEMONSTRATION

FLOW-THRU TESTS

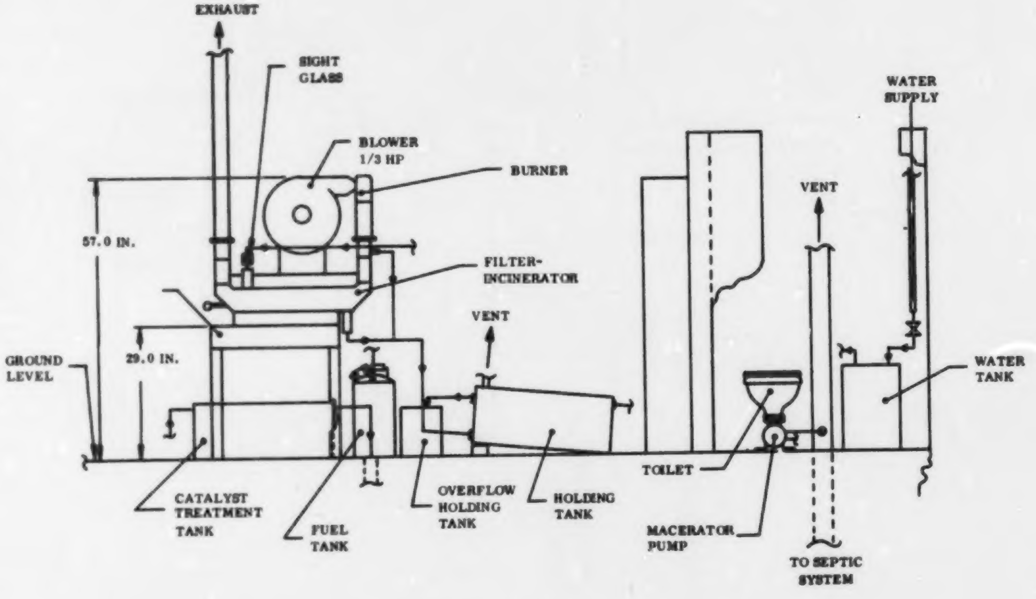
Upon completion of the laboratory system testing previously described, a prototype system was designed, fabricated, and installed in Thiokol's waste treatment test laboratory, which comprised an actual restroom equipped with a marine toilet and a prototype pleasure craft waste treatment system (Figure 15). The treatment system was located adjacent to the restroom in the same manner planned for the later vessel installation. The laboratory work force utilized the restroom. Figure 16 provides a more detailed schematic of the treatment system and Figure 17 is a photograph of the filter-incinerator assembly. Table 5 lists major system components. The filter-incinerator was equipped with three Refrasil 2-3/4 in. OD by 22 in. long filter elements resulting in a filter surface area of 4 ft^2. Operation of the system was as follows.

Macerated waste from the marine toilet collected in the holding tank until the high liquid level in the tank (as determined by a level sensor) was reached. A premeasured quantity of hypochlorite was added to the tank at this time and the batch processing of the collected waste was initiated. The liquid from the holding tank was pumped to the filter-incinerator using the 2-1/2 gpm rotary screw pump and circulated through the filter-incinerator back to the holding tank. At the same time, the 1 gpm vacuum pump was operated to draw filtrate through the filter elements and transfer this filtrate to the catalyst tank. This process continued until the level sensor in the holding tank indicated all waste had been processed. Liquid remaining in the filter-incinerator was then drained back to the holding tank, and the collected solid material was incinerated. Upon completion of the incineration cycle, the system was ready to accept another batch of sewage. The compartments in the secondary treatment tanks hold approximately 15 gal each and the average batch size processed through the system was 15 gal. Thus, the average residence time of each batch in the secondary treatment tank was the time required to process two batches of sewage. This time varied throughout the test program but was generally in excess of 12 hr.

Flow-thru testing was initiated on 22 May 1972. Forty-five batches of sewage were processed. Sewage for all but six batches was obtained from the limited flush marine toilet. In an effort to supplement the human sewage, dog food was added to six of the batches. Test results are shown on Table 6. The first 36 tests utilized the sewage from the marine toilet. The next six (37 thru 42) were conducted with dog food addition and the last three with sewage from the marine toilet. The summary table gives BOD and suspended solids data for feed sewage, filtrate, and effluent.


VACUUM PUMP
FUEL PUMP
OVERFLOW HOLDING TANK
FILTER FEED PUMP
DRAIN
ACCESS PORT
CATALYST TREATMENT TANK
TABLE
HOLDING TANK
FILTER-INCINERATOR

PLAN VIEW


EXHAUST
SIGHT GLASS
BLOWER 1/3 HP
BURNER
WATER SUPPLY
VENT
57.0 IN.
FILTER-INCINERATOR
VENT
GROUND LEVEL
29.0 IN.
WATER TANK
TOILET
CATALYST TREATMENT TANK
FUEL TANK
OVERFLOW HOLDING TANK
HOLDING TANK
MACERATOR PUMP
TO SEPTIC SYSTEM

ELEVATION VIEW

Figure 15. Building M-85 Layout, EPA Houseboat

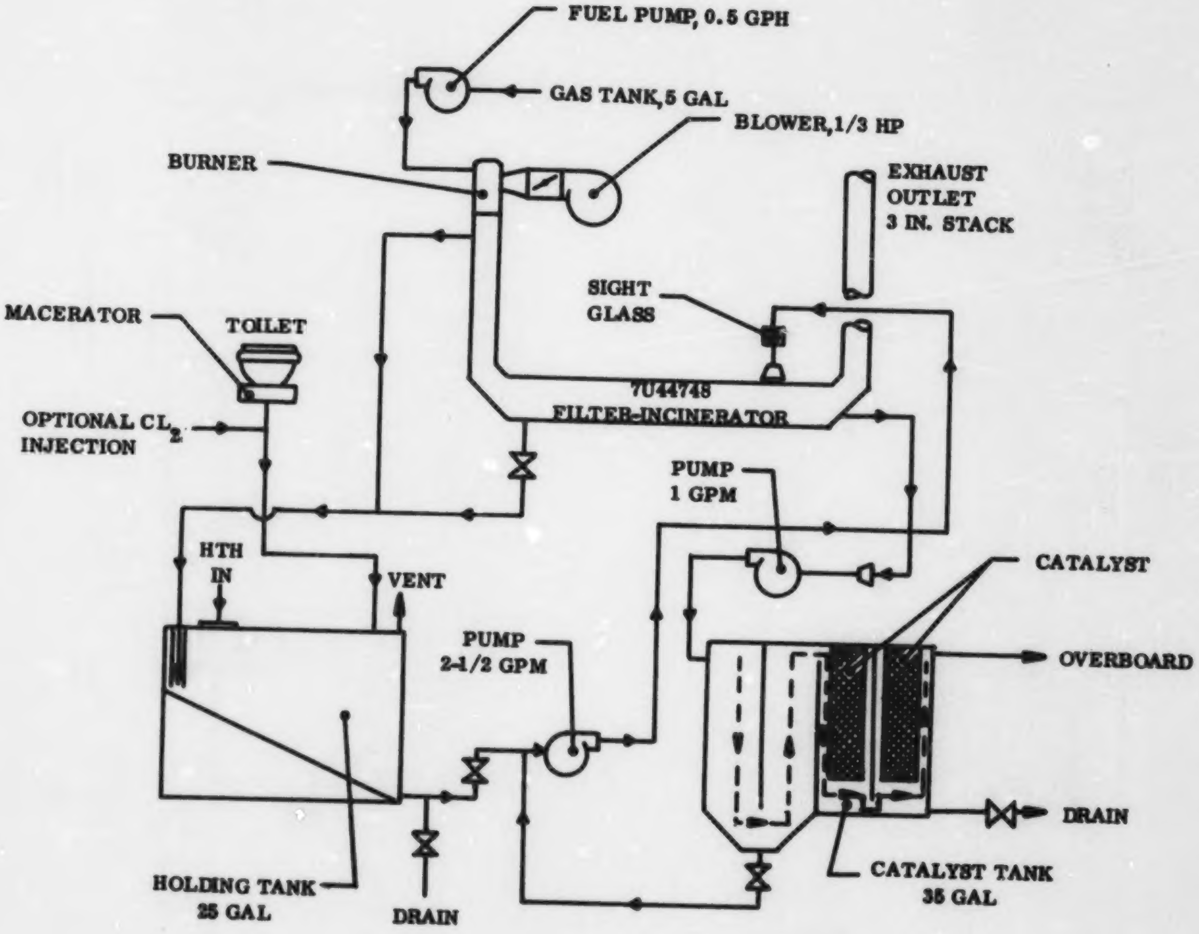

FUEL PUMP, 0.5 GPH
GAS TANK, 5 GAL
BLOWER, 1/3 HP
BURNER
EXHAUST OUTLET 3 IN. STACK
SIGHT GLASS
MACERATOR
TOILET
7U44748 FILTER-INCINERATOR
OPTIONAL CL_2 INJECTION
PUMP 1 GPM
HTH IN
VENT
CATALYST
PUMP 2-1/2 GPM
OVERBOARD
DRAIN
HOLDING TANK 25 GAL
DRAIN
CATALYST TANK 35 GAL

Figure 16. Houseboat Schematic Diagram

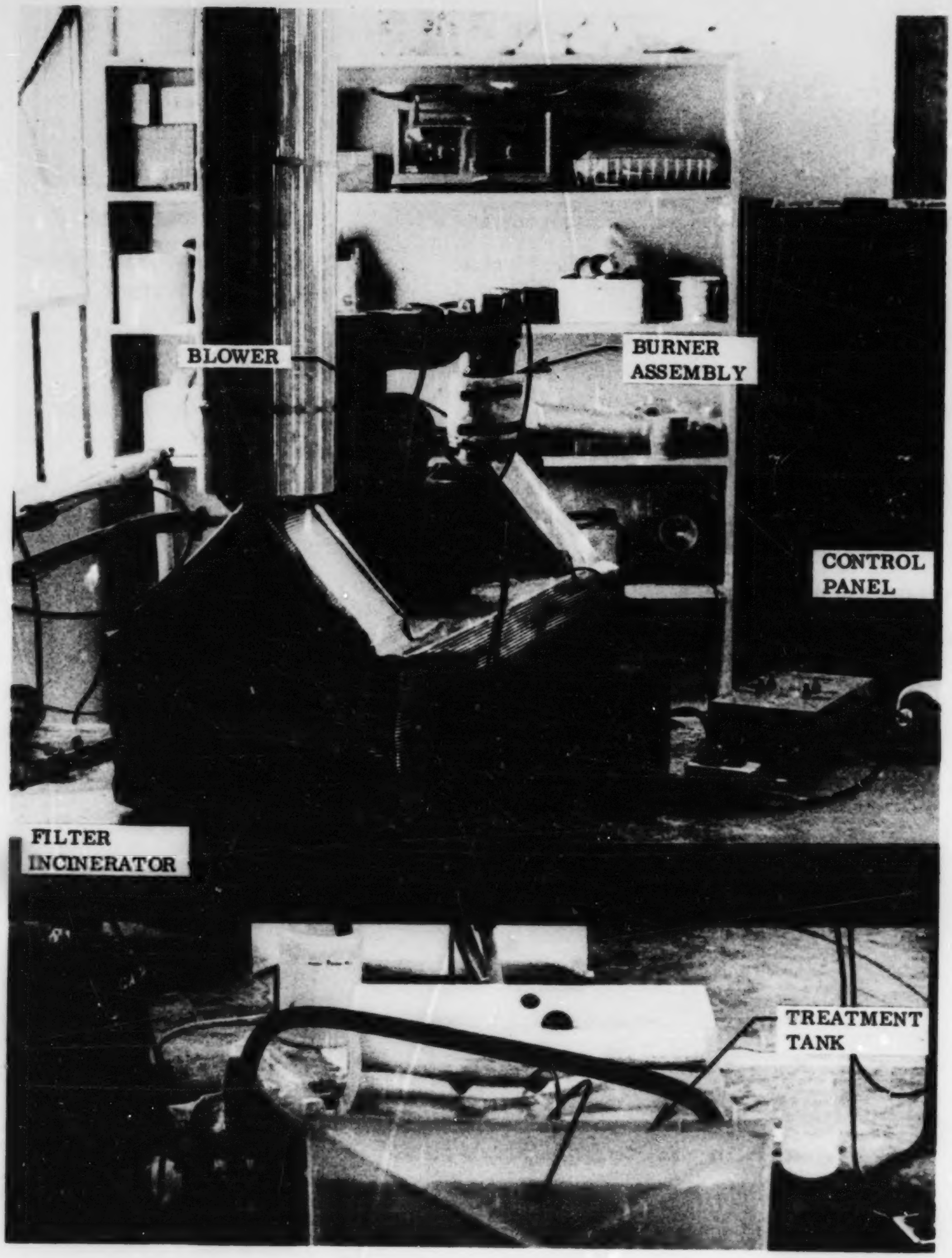

BLOWER
BURNER ASSEMBLY
CONTROL PANEL
FILTER INCINERATOR
TREATMENT TANK

Figure 17. Prototype Filter-Incinerator Assembly

TABLE 5

MAJOR FLOW-THRU SYSTEM COMPONENTS

Component	Description	Manufacturer and Model
Toilet/macerator	Limited flush marine toilet	Raritan Crown Head
Burner assembly	Fuel pump and burner	"Southwind" Model 8304A by Stewart-Warner
Vacuum pump	11 to 20 in. Hg vacuum, 1/4 hp, 115 vac	Vanton Flex-i-liner, size 18
Filter feed pump	Rotary screw pump, 2-1/2 gpm, 115 vac	Teel - W. W. Grainger's S/N 1P555
Blower	160 cfm at 5 in., 1/3 hp, 115 vac	W. W. Grainger's P/N 2C820
Holding and catalyst tank	37 gal polyethylene	Nalgene U.S. Plastics - S/N 06311
Settling tank	30 gal conical bottom polyethylene	Nalgene Series 16000
Filter incinerator	Three element filter incinerator	Thiokol

TABLE 6

SUMMARY OF SYSTEM FLOW-THRU TESTING

Test	Date	Influent Pretreat (gm HTH added)	Volume Filtered (gal)	Filtration Time (min)	Influent S/S** (mg/l)	Filtrate S/S (mg/l)	% Reduction S/S	Influent BOD (mg/l)	Effluent BOD (mg/l)	% Reduction BOD	Filtrate Treatment (ml of Superchlor added)	Incineration Time (min)	Cumulative Incineration Cycles	Notes
1	5/31	250	21	8.4	305	75	75	430	--	—	None	41	1	
2	5/31	None	19	11.5	242	52	80	--	--	--	None	40	2	
3	6/1	200	9	--	2,820	133	96	950	--	--	None	44	3	
4	6/1	None	19	--	965	200	80	700	--	--	1,250	41	4	Replaced all filter elements after this test. Original elements improperly installed. Two ply B-2 1/2 elements were reinstalled.
5	6/2	250	25	15	1,035	202	80	720	108	85	None	75	1	
6	6/5	None	15	7	1,855	180	90	814	219	73	--	65	2	
7	6/5	None	15	7	1,690	4	99	914	188	79	--	35	3	
8	6/6	250	15	10	5,540	173	97	2,820	327	88	1,200	30	4	
9	6/6	250	13	8.4	7,675	48	99	3,270	307	91	1,200	25	5	
10	6/7	None	20	16	320	110	66	541	130	76	1,200	75	6	
11	6/7	None	20	15	218	25	89	385	--	--	1,200	30	7	
12	6/8	None	15	9.4	520	205	60	475	79	83	1,200	40	8	
13	6/8	None	15	9.4	--	--	--	--	--	--	1,200	45	9	
14	6/8	None	15	9.6	--	--	--	--	153	--	1,200	30	10	
15	6/9	None	10	7	5,860	285	95	1,894	--	--	1,200	?	11	
16	6/12	None	15	8.3	1,678	112	93	846	--	--	1,200	None	--	
17	6/12	None	15	8.9	902	113	88	846	--	--	1,200	None	--	
18	6/12	None	15	9.0	3,435	132	97	1,132	--	--	1,200	80	12	
19	6/13	None	15	10	1,168	140	87	--	--	--	1,200	None	--	
20	6/13	None	15	10	1,820	66	96	--	--	--	1,200	None	--	
21	6/13	None	15	11	908	72	92	--	--	--	1,200	60	13	
22	6/14	None	20	23	--	--	--	--	--	--	?	65	14	
23	6/14	None	15	14	705	73	89	--	66		600	60	15	
24	6/16	None	20	14.8	--	41	--	--	--	--	500	None	--	
25	6/19	None	15	34	2,340	69	99	1,064	179	83	?	None	--	
26	6/19	None	15	54	1,008	--	--	1,094	--	--	1,000	75	16	
27	6/20	None	15	8.8	616	108	82	850	165	80	?	None	--	
28	6/20	None	15	10.8	600	78	86	514	69	92	?	None	--	
29	6/20	None	15	11.5	720	79	89	974	66	93	?	60	17	
30	6/21	None	25	14.3	--	--	--	--	--	—	?	65	18	
31	6/21	None	12	8.3	--	--	--	--	--	—	?	60	19	
32	6/22	None	21	15	--	51	--	--	--	—	?	None	--	
33	6/23	None	12	8.8	1,750	52	97	--	--	—	750	30	20	
34	6/26	None	12	7.6	605	20	97	--	--	--	?	45	21	
35	6/29	None	9	10	--	--	--	--	--	—	1 pt	45	22	
36	6/30	None	8	8	--	--	--	--	--	--	1 qt	2	23	
37*	8/21	None	15	25	1,450	21	98	1,060	--	--	1 qt	None	--	
38*	8/21	None	10	30	760	20	97	683	--	--	2/3 qt	35	24	
39*	8/22	None	15	30	4,002	130	99	1,456	541	63	2 qt	50	25	
40*	8/23	None	11	30	8,400	29	99	3,760	388	90	2 qt	40	26	
41*	8/24	None	9	30	650	40	93	2,330	416	82	6 qt	None	--	Replaced outer ply of all elements after test.
42*	8/25	None	15	30	5,005	38	99	3,700	1,140	69	7 qt	60	1	
43	8/28	None	15	25	534	25	96	2,260	512	77	7 qt	70	2	
44	8/29	None	15	15	--	--	--	--	--	--	8 qt	70	3	
45	8/30	None	10	10	4,252	337	92	3,400	160	95	6 qt	45	4	

---

*Tests with dog food addition

**S/S = suspended solids

The effluent BOD values listed in Table 6 range from 66 mg/l to 327 mg/l, excluding the tests conducted with dog food added to the sewage. While BOD values in excess of 150 mg/l are considered high, they must be evaluated on the basis of the feed values of BOD which were generally high, ranging from 300 to as high as 3,400 mg/l. An average BOD reduction of 82% was obtained. Additional chemical treatment to further reduce BOD was considered but not investigated due to the issuance of a program stop order and the subsequent program redirection to evaluate a zero discharge system.

Runs 37 thru 42 had high effluent BOD values (between 388 and 1,140 mg/l) due to the type of sewage used (a mixture of human sewage and dog food) in the tests. Dog food contains a quantity of fat and numerous other ingredients not normally found in actual body waste. Dog food proved useful in checking filtration performance of the system, but did not give an accurate indication of the system's BOD removal capability and was discontinued.

Performance of the filter elements with suspended solids reduction of 60 to 90% was considered good. Durability of the elements was also good, although the outer ply of the initially installed elements was observed to be torn after the first four tests. This failure was determined to be caused by faulty installation. After replacement of the initial elements with new elements, no element deterioration was observed for 37 filtration cycles (26 incineration cycles).

During the dog food tests, filter thru-put dropped to about 15 gal before incineration was needed. In an attempt to improve thru-put, a water backwash cycle was initiated. Inspection of the elements after test number 41 showed a small tear in the outer ply of one element, but no deterioration of the inner plies. The outer ply of filter cloth was replaced on all three elements.

The three filter elements contained a total of 4 ft^2 of filtration area. Even with the heavy sewage feed during tests with dog food, 15 gal of sewage were processed through the elements indicating an adequate surface area for filtration. Runs 27 thru 29 represented a total filter thru-put of 45 gal before incineration as did runs 31 thru 33, thus verifying the adequacy of the filter elements.

Figure 18 depicts a typical incineration cycle. An exit temperature of over 800° F is necessary for complete combustion of solids. Several runs were stopped before the 800° F exit temperature was reached; inspection of the interior of the incinerator revealed several areas having unburned solids. Later runs were made with the blower shut off simultaneously with the fuel, and no adverse effects resulted.

During all incineration cycles, odors were never detected in the vicinity of the equipment or from the exhaust stack. Visible discharge of smoke or particulate matter was not detected in the exhaust.

RUN NO. 3 WITH FILTER-INCINERATOR USING
3 REFRASIL ELEMENTS

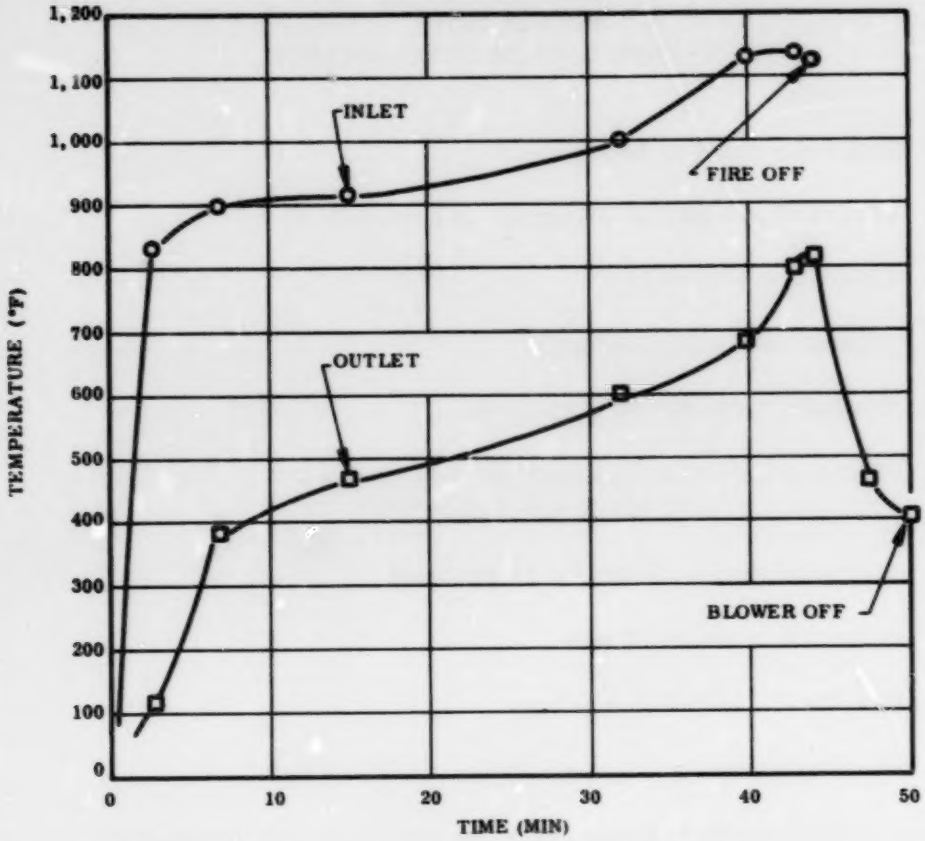


Figure 18. Typical Temperature Profile

From the preceding tables and other operating experience, expected operating parameters were developed for the flow-thru system as shown on Table 7.

ZERO DISCHARGE TESTS

To demonstrate the feasibility of using a recirculating system onboard pleasure craft, certain of the components used in the flow-thru tests were utilized to treat the Building M-85 flushwater for reuse.

The system was assembled similarly to that shown in Figure 15. The fresh water supply line to the flushwater tank was capped and treated effluent from the catalyst tank was recycled to the flushwater tank instead of discharging the effluent. Since the addition of solid hypochlorite would have resulted in buildup of the dissolved salt level in the system and liquids in the system would have increased by

TABLE 7

PROJECTED
FLOW-THRU SYSTEM PERFORMANCE

BOD reduction = 90 to 95%

SS reduction = 90% by filtration, 95% overall

Effluent pH = 10 to 12

Effluent coliform = negligible

Effluent Cl_2 level = 50 to 100 ppm

Chlorine use = 1 gal Clorox/7 gal feed sewage at 2,000 to 4,000 ppm BOD

Filtration time = 15 min for 15 gal batch

Incineration time = 45 min

Gasoline/Incineration = 1/2 gal

Electrical power:

Fuel/spark =	**3 amp, 12 v, 45 min**	**(0.025 kwh)**
Filter feed =	**7 amp start, 3 amp run, 115 v, 15 min**	**(0.086 kwh)**
Blower =	**15 amp start, 3 amp run, 115 v, 50 min**	**(0.288 kwh)**
Vacuum =	**15 amp start, 3 amp run, 115 v, 15 min**	**(0.086 kwh)**
Total power use per cycle		**0.460 kwh**

liquid hypochlorite addition, initial zero discharge tests were conducted using an electrolytic process to generate hypochlorite. In this process, the only chemical addition necessary is sodium chloride, and electrolytic cells are used to convert the sodium chloride to sodium hypochlorite. PEPCON cells, manufactured by Pacific Engineering and Production Company of Nevada, were selected for use in the system.

There is a contribution to the salt level in the system by body waste; however, prior experience with other systems has shown this to be negligible.

Normal ship power (12 v) is used to power the PEPCON cell system. Three PEPCON cells (10 in^2 each) are connected in series electrically with parallel liquid flow. This scheme allows minimum hydraulic pressure drop and a voltage drop of 4 v across each cell. With a 4% NaCl solution, an amperage drain of 5 to 6 will result. The current and rate of hypochlorite production is adjusted by changing the salt concentration.

The system used a 1/35 hp pump (115 v, 200 w) to circulate system liquid through the PEPCON cells; each cell had a flow of about 1/4 gpm.

The system was filled with salt water on 1 September and the solution was circulated through the PEPCON cells to generate the hypochlorite level. The hypochlorite/salt solution was then used as the M-85 toilet flush media. On 7 September sufficient liquid waste had been collected for the initial filtration run. Since current levels in the PEPCON cells were dependent upon the salt level (voltage is fixed), there was an initial adjustment of salt levels to find the proper operating level. The system had a poor electrical connection upon startup and excess salt was added. Later, the faulty connection was discovered and the solution had to be diluted to bring cell current down to the 5 to 6 amp range. Operation was unstable the first week as solution was dumped and replaced with fresh salt water. After the startup period, no difficulties were experienced with the PEPCON system and current levels were very stable. The data from this initial test provided sufficient information for the preliminary Phase II design.

PRELIMINARY PHASE II DESIGN

System testing in Phase I indicated that the concept of a zero discharge system was sound. There were several modifications suggested by the test results which would greatly simplify system manufacture, installation and operation.

During the filtration tests, it was observed that a filtration rate of 100 ml/min was possible without using a vacuum pump. The new Phase II filter-incinerator design was consequently based on gravity flow during filtration which allowed the unit to be placed directly above the secondary treatment tank and eliminated the need for one pump.

Figure 19 depicts the basic system layout planned for the pleasure craft. A portion of the closet located next to the toilet was chosen to house the treatment system. The mode of operation (based upon use of a marine toilet) was as follows:

1. The toilet and holding tank, 1 and 2, was precharged with a hypochlorite solution. The Monomatic toilet held about 4 gal of solution which was used for a number of flushes.

2. After 30 to 40 uses, the holding tank contents, 2, were pumped out into the filter-incinerator, 3, for gravity filtration.

3. The holding tank was then refilled with treated water from the catalyst tank, 4.

4. Filtrate via gravity entered the catalyst tank, 4 (filtration required 10 to 14 hr).

5. After a majority of the filtrate entered the catalyst tank, a pump automatically initiated circulation through the PEPCON cells, 5. A timer stopped circulation after adequate treatment.

6. Prior to pumping another batch into the filter, the solids remaining on the filter were incinerated.

The desired degree of automation was not initially determined. It appeared possible that all operations could be controlled by a timer and the entire filtration/incineration/treatment cycle could occur with no operator attention after initiation of the cycle (pushing the START button). It was decided to initiate testing in a semiautomatic mode in the laboratory and incorporate automation at a later date.

System Design

The zero discharge system concept for Phase II provided a safe, compact waste treatment package with the potential for low initial cost and low operating costs. Virtually all of the system components were located in the closet adjacent to the washroom, as shown in Figure 19. The toilet, holding tank, and recirculating flush pump were an integral unit to minimize the loss of usable living space in the washroom. All components were readily accessible for routine maintenance.

The 30 gal catalyst tank was constructed of Nalgene to provide the necessary corrosion resistance. An aluminum support cage (Figure 20) was provided to

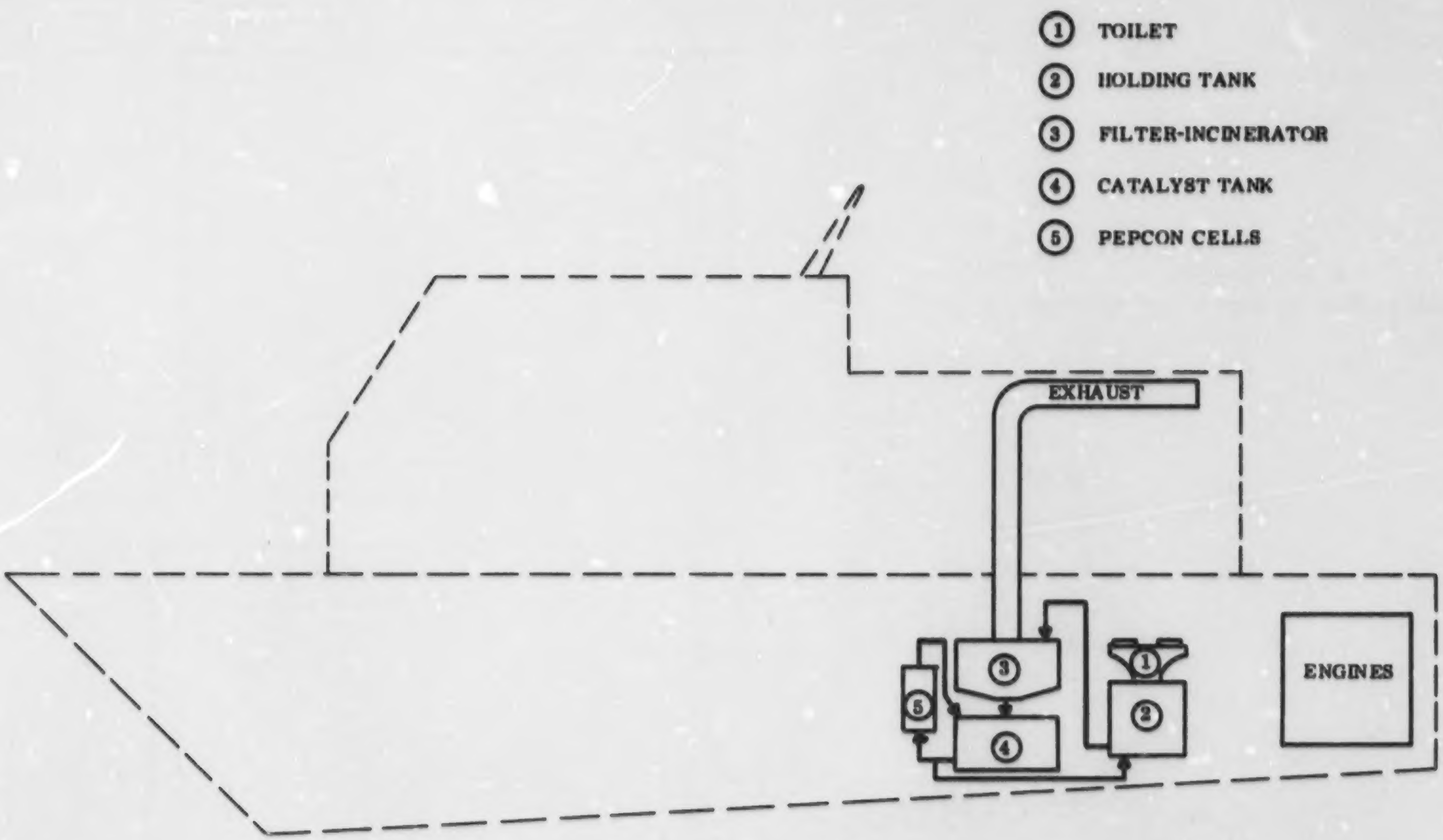
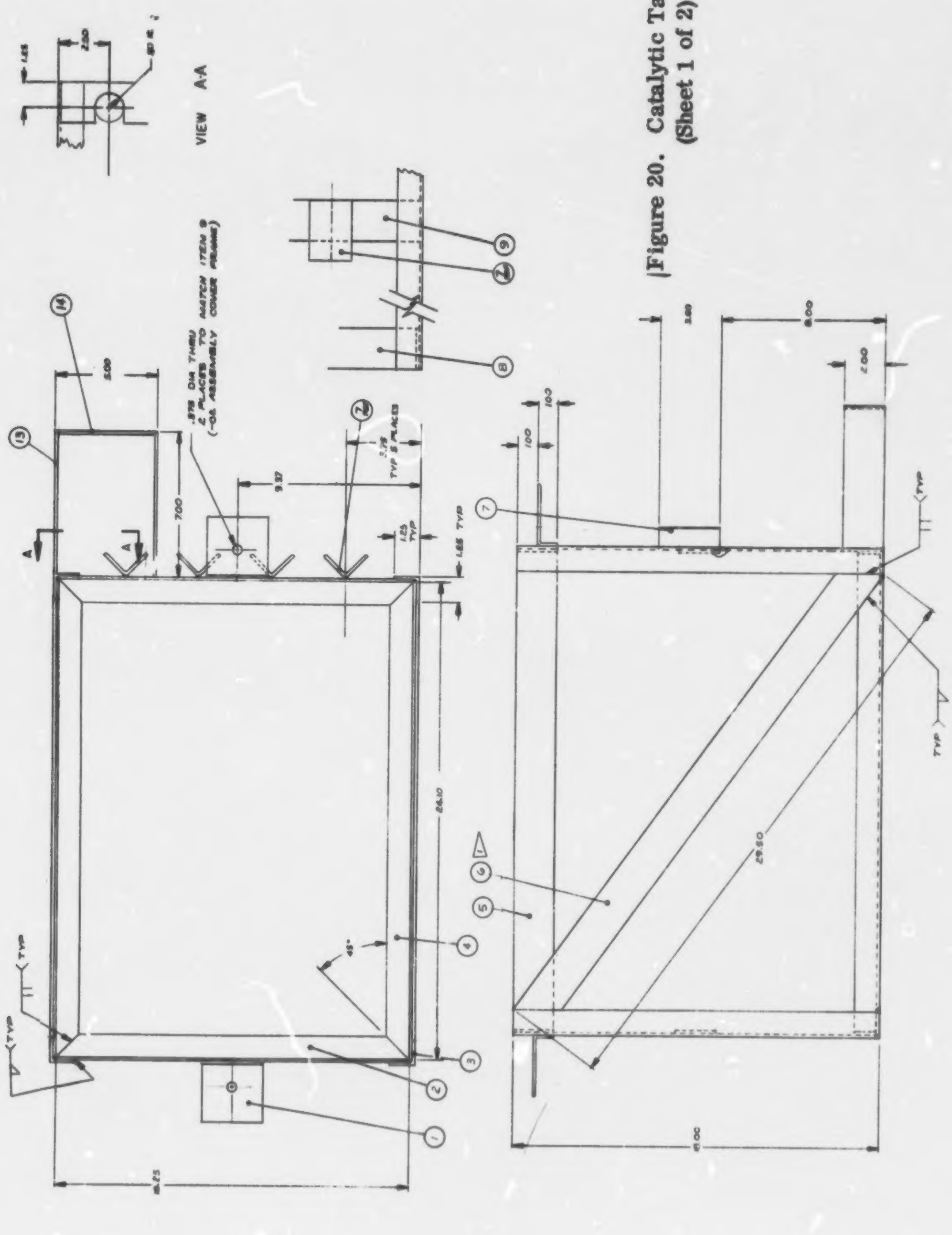

① TOILET
② HOLDING TANK
③ FILTER-INCINERATOR
④ CATALYST TANK
⑤ PEPCON CELLS
EXHAUST
ENGINES
①
②
③
④
⑤

Figure 19. Zero Discharge Installation Layout



VIEW A-A
A
A
.375 DIA THRU 2 PLACES TO MATCH ITEM 9 (-03 ASSEMBLY COVER FRAME)
TYP
45°
18.25
26.10
29.50
15.00
9.37
7.00
5.00
8.00
3.00
2.00
1.00
1.00
1.25 TYP
1.85 TYP
1
2
3
4
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6
7
8
9
12
13
14

Figure 20. Catalytic Tank Support
(Sheet 1 of 2)

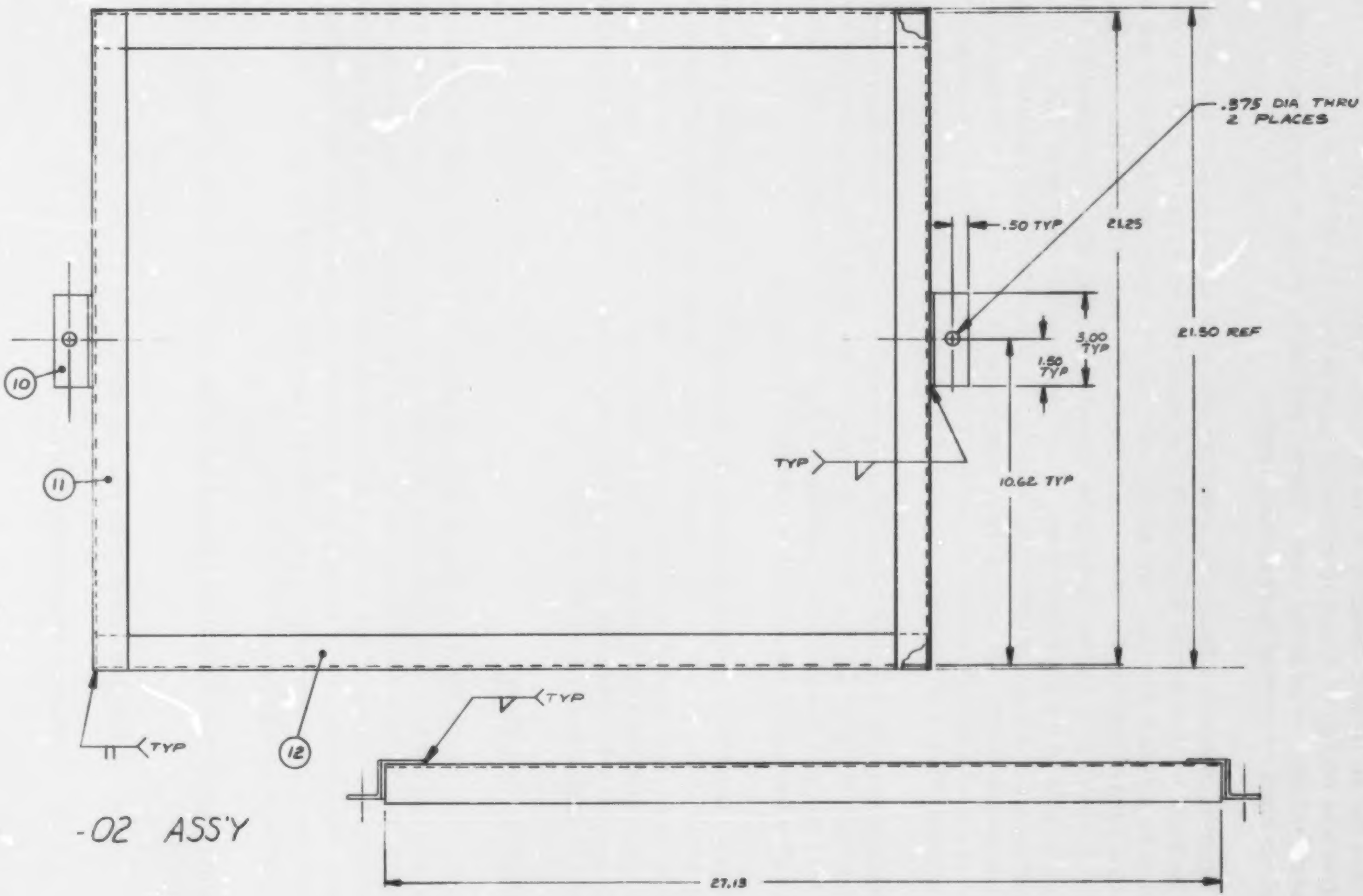
.375 DIA THRU
2 PLACES
.50 TYP
21.25
21.50 REF
3.00 TYP
1.50 TYP
10.62 TYP
TYP
TYP
TYP
10
11
12
-02 ASS'Y
27.13

Figure 20. Catalytic Tank Support
(Sheet 2 of 2)

increase the structural integrity of the tank and support the PEPCON cells. The catalyst was contained either in individual porous bags inside the tank or in separate columns outside the tank. Valves and piping in the system are either stainless steel or corrosion resistant plastic.

The filter-incinerator (Figure 21) was constructed of stainless steel throughout. The Refrasil heat resistant filter cloth was supported by a porous plate and held in place by a retaining ring. Hot gases provided by a commercial blower and a gasoline burner entered the incinerator tangentially just above the filter media to induce a vortex flow pattern to promote complete combustion. Temperature taps were provided in the prototype model to monitor possible cold spots and air flow requirements. A damper valve was installed in the exhaust stack to control combustion temperature. An access hatch was located in the top of the incinerator for removal of ash and replacement of the filter cloth. The entire incinerator and exhaust stack was insulated and tagged for the protection of personnel.

Electric power was supplied by a 110 vac generator on board the pleasure craft. Direct current power for the PEPCON hypochlorite generators was supplied by a standard automotive-type battery charger. Fuel for the burner was taken from the craft's fuel tanks via a small commercial fuel pump.

The entire treatment system (Items 3, 4, and 5 of Figure 19) occupied a volume 31 by 29 by 40 in. (L x W x H). On small crafts, with limited interior space, the system could be placed in a weatherproof cabinet and then installed on deck. There was also the option of separating components to fit available space. The basic approach for Phase II was to evaluate the Phase II design in the laboratory prior to installation aboard the vessel.

Laboratory Test Phase

The objective of the Phase II laboratory test phase was to fabricate and evaluate the system prior to actual field tests on board the boat. The initial system was installed in a Thiokol facility for use by laboratory personnel. The system consisted of a low volume flush toilet, a filter-incinerator for removal and disposal of suspended solids, and a method for addition of chlorine to remove the color and disinfect the wastewater. The treated water was stored for reuse. Four basic system configurations were tested.

Configuration I--Configuration I consisted of the following items of major equipment:

1. A Raritan crown head marine toilet.

2. A vacuum filter-incinerator.

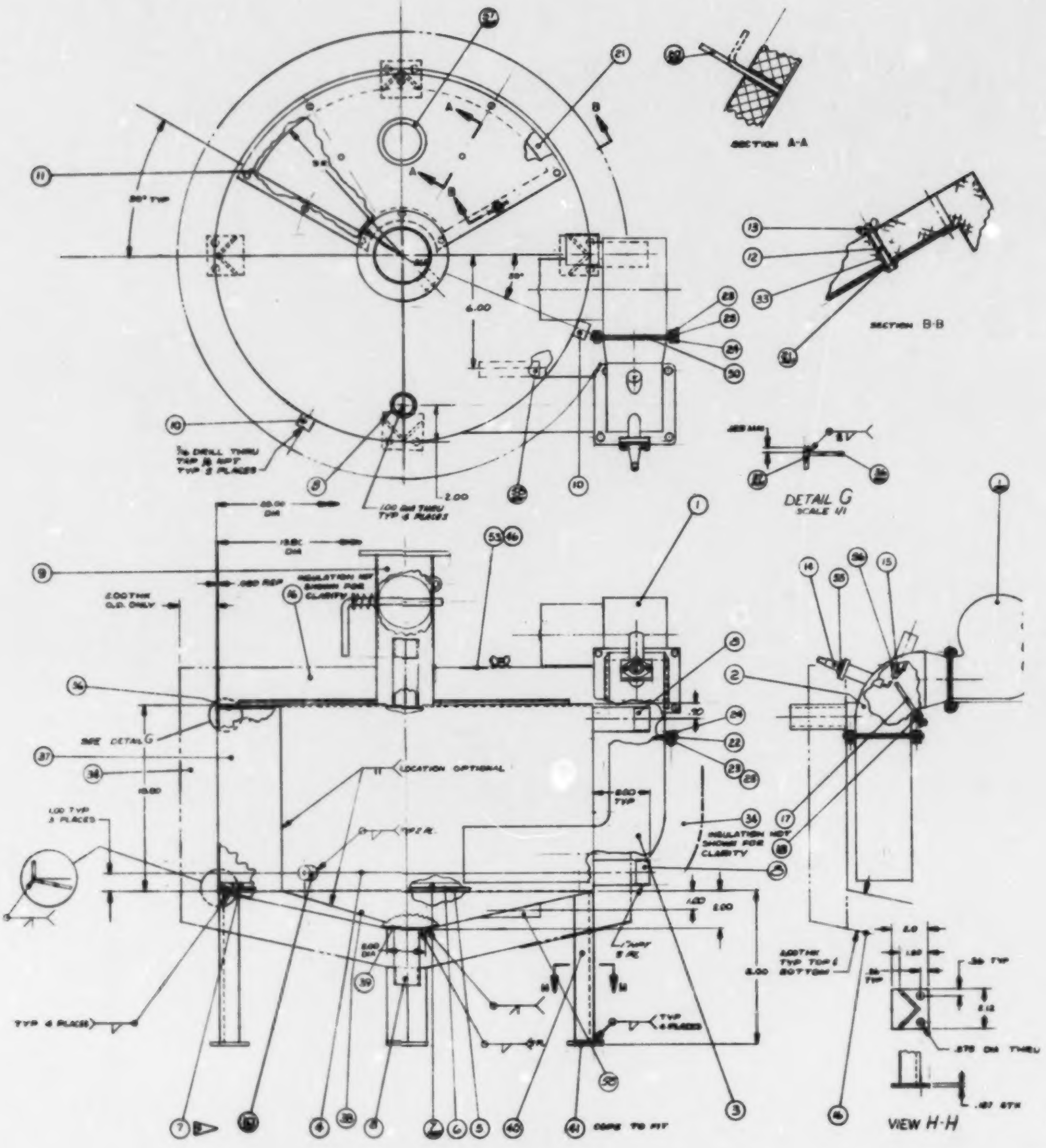
SECTION A-A
SECTION B-B
6.00
2.00
DETAIL G
SCALE 1/1
INSULATION NOT SHOWN FOR CLARITY
SEE DETAIL G
LOCATION OPTIONAL
TYP 4 PLACES
COPE TO FIT
VIEW H-H

Figure 21. Incinerator Blower Assembly
(Sheet 1 of 2)

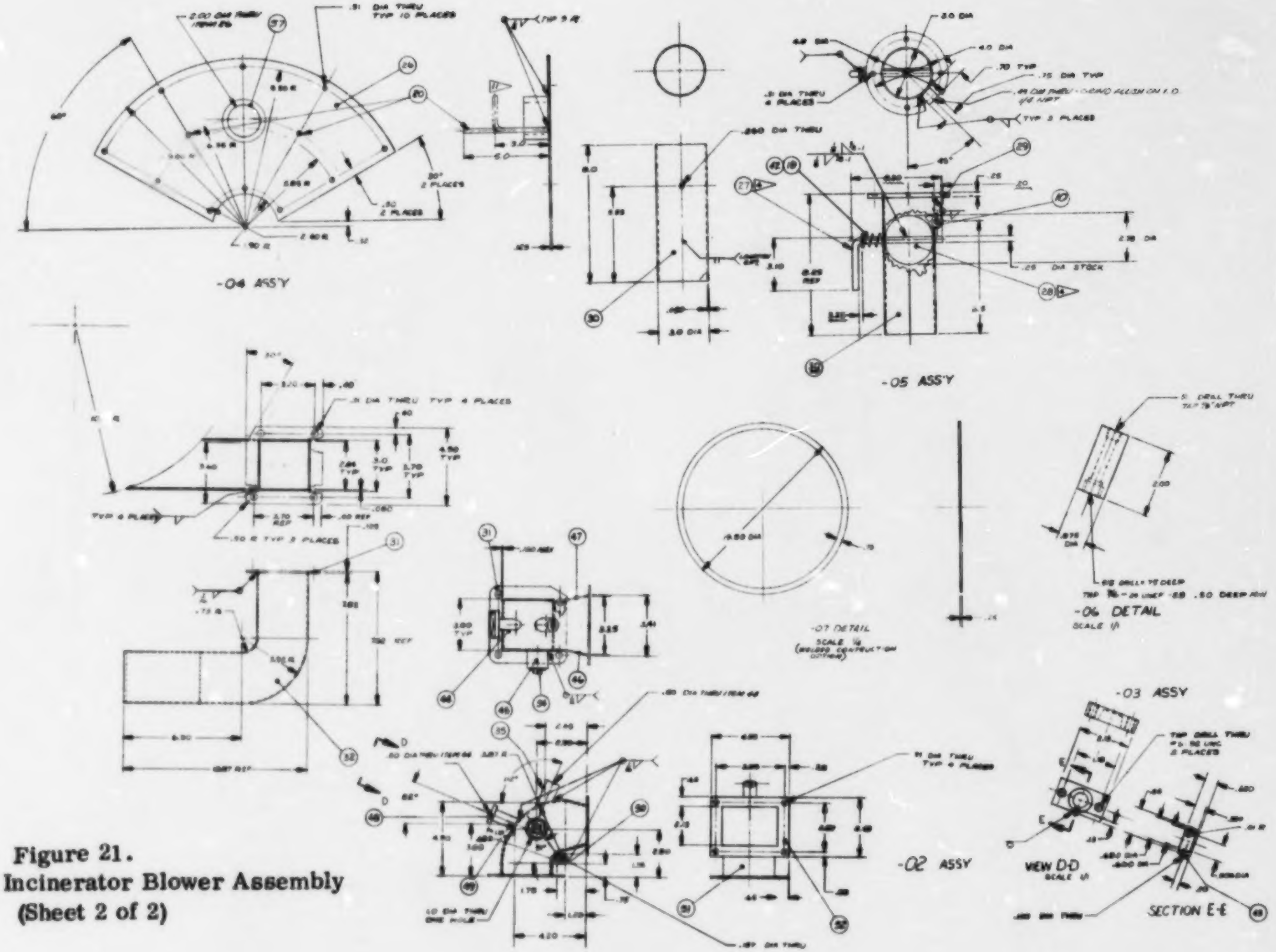
-04 ASS'Y
-05 ASS'Y
-07 DETAIL
SCALE 1/4
(WELDED CONSTRUCTION OPTION)
-06 DETAIL
SCALE 1/1
-03 ASSY
-02 ASSY
VIEW D-D
SCALE 1/1
SECTION E-E

Figure 21.
Incinerator Blower Assembly
(Sheet 2 of 2)

3. Four 10 in^2 electrolytic cells.

4. Catalyst.

The system was initially charged with salt water. The water was pumped, on demand, to the marine toilet for flushwater. The wastewater was collected in a surge tank and held for subsequent treatment. Periodically the wastewater was pumped to the filter-incinerator for suspended solids removal.

Filtrate was withdrawn from the filter with a positive displacement pump and transferred to a treatment tank. At the conclusion of the filtration cycle, the filter-incinerator was drained and the filter cake incinerated in place.

The filtrate was circulated through the electrolytic cells and catalyst for chlorination. The treated water was stored for reuse.

This system was tested from 7 Sep until 24 Sep 1972. An operation log for system operation during this period is presented in Table 8. Samples of treated water were removed periodically for analysis. The results of these analyses are presented in Table 9 defining system performance. Suspended solids concentrations ranged from 162 to 800 mg/l. BOD concentrations ranged from 95 to 1,500 mg/l. Coliform tests were negative. Testing was terminated when a piping connection failed and the water inventory was lost from the system.

Configuration II--The only difference between Configurations I and II was the substitution of a Monomatic toilet in Configuration II.

The system was initially charged with chlorinated salt water. Salt water (4 gal), containing a chlorine concentration of 275 ppm, was added to the holding tank of the Monomatic toilet. These 4 gal were recycled through the toilet bowl during each flush sequence. After several uses, the 4 gal of wastewater were pumped to the filter-incinerator for suspended solids removal. System operation was the same as Configuration I.

This system was tested from 27 Sep to 9 Oct 1972. Objectionable odors prompted the addition of several commercial masking agents, Fresh Up (quaternary ammonium salt) and T-5 (zinc sulfate), to the Monomatic holding tank. These chemicals were not compatible with the wastewater and did not provide satisfactory results. Testing was terminated on 9 Oct 1972. Limited analytical data obtained during this test period are presented in Table 9 indicating suspended solids and BOD concentrations of 492 and 582 mg/l, respectively. Coliform tests were negative.

Configuration III--Configuration III was the same as Configuration II, except that a modified Monomatic toilet was used.

TABLE 8

ZERO DISCHARGE OPERATION LOG

Test Configuration	Date	Filtration Volume (gal)	Inventory (gal)	Remarks
I	9/7	11	--	--
	9/8	14	35	--
	9/13	16	27	Dumped 7 gal excess
	9/18	18-1/2	31	--
	9/20	--	33-1/2	--
	9/22	18	36-1/2	--
	9/24	--	2	Connection ruptured, losing system inventory
II	9/27	--	--	Started recirculation of toilet contents as flush-water
	10/2	17	21	Bag filter used
	10/5	5	--	Gravity filtration with flat element

TABLE 9

ZERO DISCHARGE ANALYTICAL RESULTS
TREATMENT TANK

Test Configuration	Date	Before or After Filtrate Addition	BOD (mg/l)	S/S (mg/l)	Chloride (ppm Cl^-)	Coliform	pH	Chlorine (ppm)	Virus
I	9/7/72	After	310	282	32,684	None	--	--	--
	9/8/72	Before	95	--	21,010	None	--	--	--
	9/8/72	After	283	--	22,670	None	--	--	--
	9/13/72	Before	217	254	23,201	None	--	--	--
	9/13/72	After	672	198	23,257	None	--	--	--
	9/18/72	Before	326	162	25,022	None	--	--	--
	9/18/72	After	1,500	494	23,684	None	--	--	--
	9/22/72	Before	475	246	24,193	None	--	--	--
	9/22/72	After	1,220	800	22,050	None	--	--	--
			New Solution						
II	10/2/72	After	582	492	--	None	--	--	--
			New Solution						
III	10/13/72	After	305	112	--	None	--	--	--
	10/18/72	Before	170	--	--	None	--	--	--
	10/18/72	After	370	--	--	None	--	--	--
	10/20/72	Before	319	100	--	None	--	--	--
	10/20/72	After	728	142	--	None	--	--	--
	10/25/72	After	730	--	--	--	--	--	--
IV	11/30/72	Filtrate	1,338	--	--	--	--	--	--
	11/30/72	After HTH addition	696	--	--	--	--	--	--
	12/19/72	--	1,147	--	--	--	7.15	158	--
	1/2/73	--	--	--	--	--	--	--	Neg
	1/22/73	--	1,692	--	--	--	6.4	348	--

The system was charged with 32 gal of 1.5% salt water. The Monomatic toilet was modified such that freshly treated water was supplied for each flush sequence. The wastewater was accumulated in the holding tank of the Monomatic toilet. Periodically, the holding tank contents were transferred to the filter-incinerator for suspended solids removal. System Operation was the same as Configurations I and II.

This system was tested from 10 Oct to 20 Nov 1972. An operation log for this period is presented in Table 10. Samples were withdrawn from the system periodically for analysis (Table 9). Suspended solids concentrations ranged from 100 to 142 mg/l. BOD concentrations ranged from 170 to 730 mg/l. Coliform tests were negative.

During the last 2 to 3 weeks of this test period, components for the onboard model of the houseboat waste treatment system were received and intermittently implemented in the laboratory tests for evaluation and checkout. These tests are described below:

Gravity filter-incinerator evaluation--After fabrication of the filter-incinerator, several days were required to adjust the burner to deliver a stable flame. A burner cup was added to stabilize the flame and insure positive ignition. With a wide open damper, the gases entering the incinerator were 1,050° to 1,150° F.

On 17 Nov 1972, approximately 10 gal of concentrated Monomatic wastes were filtered. The starting filtrate rate was 0.4 gpm, after 12 min the rate dropped to 0.25 gpm. Total filtration time was 2 hr. Two factors caused the filtration rate to decrease during the filtration cycle: plugging and decrease of head (liquid height above the filter).

The incineration time was 10 min, which was the length of time for the outlet temperature to approach 1,150° F. At the end of the incineration, the temperature switch located just above the filter cloth was starting to cycle indicating a temperature at this point of near 1,050° F. Inspection of the filter upon opening the incinerator showed complete incineration with no unburned material remaining.

The second batch of material would not filter by gravity alone; it was necessary to run the vacuum pump briefly to initiate flow. After the brief run with the pump, filtration continued solely by gravity at about 0.065 gpm. The first two runs were made with macerated sewage (a "MONO" pump was installed on the outlet of the Monomatic toilet). On the third run, the sewage was transferred to the filter via a diaphragm pump. The unmacerated sewage resulted in a 20 min filtration time for 8 gal of filtrate with gravity flow, substantially better results than experienced with macerated sewage. Indications were that use of a transfer

TABLE 10

ZERO DISCHARGE OPERATION LOG
TEST CONFIGURATION III

Date	Liquid Discharge	Solid Discharge	Filtration Volume (gal)	Inventory (gal)	Remarks
Oct 10	4	1	--	20	Recharged system
Oct 11	14	1	--	--	--
Oct 12	9	3	--	32	Added 12 gal fresh water
Oct 13	10	2	20	--	--
Oct 16	7	3	--	33	--
Oct 17	9	4	--	--	--
Oct 18	17	2	16	32	--
Oct 19	8	3	--	--	--
Oct 20	7	2	--	--	--
Oct 23	7	3	--	--	--
Oct 24	8	2	--	--	Changed toilet flush switch to momentary contact
Oct 25	10	2	6	--	--
Oct 26	13	2	--	--	--
Oct 27	13	1	13	30	--
Oct 30	12	3	--	--	--
Oct 31	16	2	--	--	--

pump that does not break up the sewage solids will result in much shorter filtration times and may eliminate the need for a vacuum pump.

100 in^2 electrolytic cell evaluation--For simplification of design, one larger PEPCON cell was evaluated in place of the four small cells. The 100 in^2 cell was first run on 7 Nov 1972, treating a 20 gal batch of sewage with a BOD of about 1,315 ppm. After 2 hr of treatment, the solution was decolorized from a dark brown to a light yellow and had a Cl_2 residual of about 200 ppm. Four additional hours of treatment did not change the color and raised the Cl_2 level to 650 ppm.

An extended run was started 17 Nov 1972. Results are given in Figure 22. Concentrated sewage (24-1/2 gal) was treated with the 100 in^2 PEPCON cell. Cell amperage was maintained near 1 amp/in^2. Color removal was indicated by the transmittance increase of the solution. Initial transmittance was 5%, after 3 hr was 22%, after 5 hr was 50%, after 8 hr was 60%, and after 35 hr of treatment was 91%. A true color test was not performed; however, the transmittance gives an indication of solution clarity. After several hours of treatment the solution was light yellow and was clear after 35 hr.

Configuration IV--Configuration IV consisted of the following items of major equipment and unit operations:

1. A Monomatic toilet (modified).

2. A gravity filter-incinerator.

3. Chemical (HTH) addition.

The system was charged with 20 gal of effluent from the Configuration III test.

Flushwater was supplied to the toilet in one of two modes, as described below. The accumulated wastewater was transferred to the filter-incinerator for suspended solids removal. The filtrate drained by gravity flow into a treatment tank. Calcium hypochlorite pellets or powder (tradename "HTH") was added to the treatment tank as a source of chlorine. An extended reaction period (overnight) was used in lieu of catalyst used in previous test configurations. The treated water was stored for reuse.

The system was tested from 21 Nov to 20 Dec 1972 with the Monomatic toilet modified to provide freshly treated water for each flush sequence. The system was operated from 20 Dec 1972 to 23 Jan 1973 with the Monomatic toilet modified to recirculate the toilet chamber contents during each flush cycle. Operating data obtained during the test period are presented in Table 11. The analytical test results are presented in Table 12. The continual addition of chemicals to

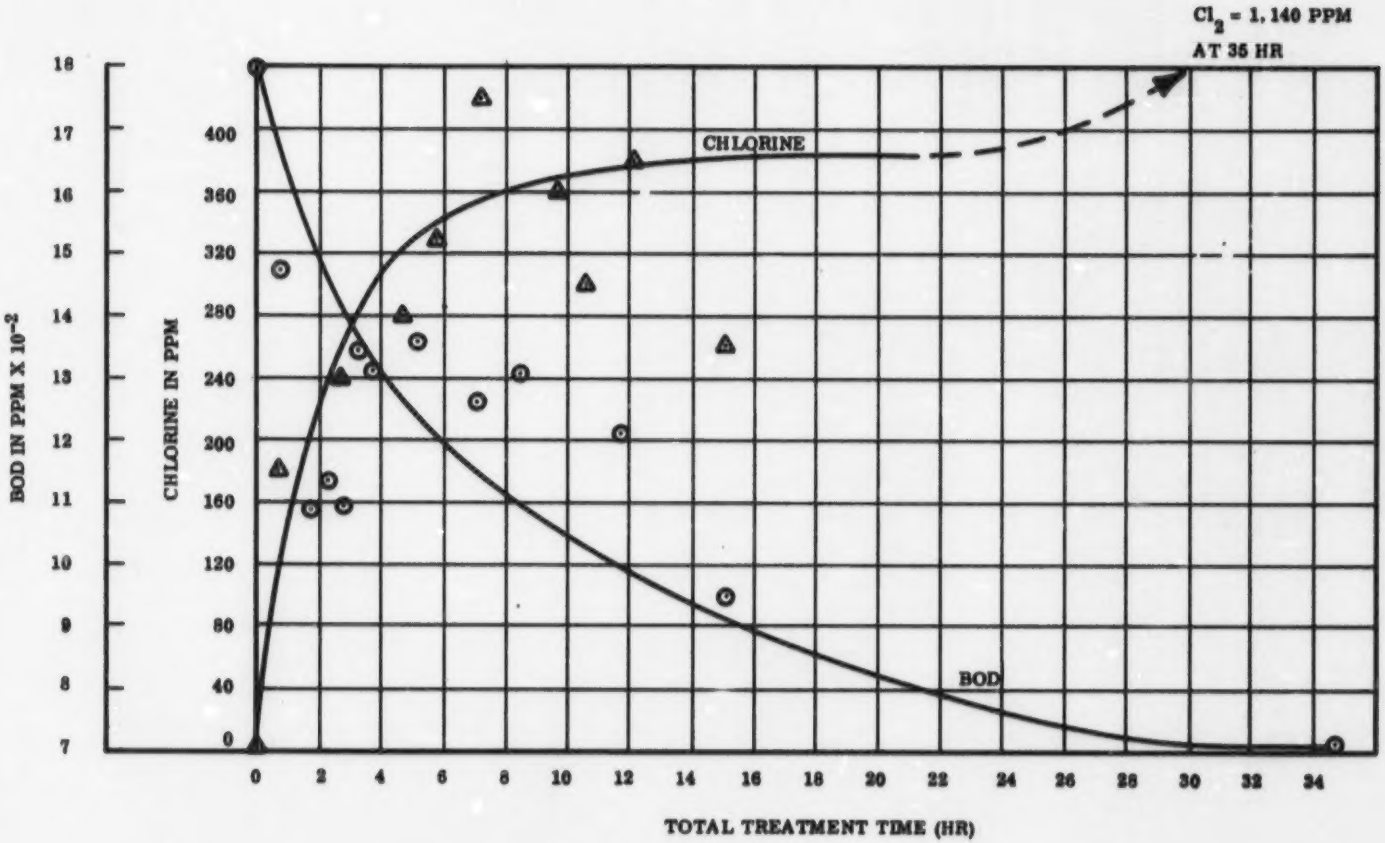

Figure 22. Treatment of 24-1/2 Gal Sewage With a 100 In^2 PEPCON Cell at a Nominal of 1 Amp/In^2

TABLE 11

ZERO DISCHARGE OPERATION LOG
TEST CONFIGURATION IV

Date	Uses in Batch		HTH Added (gm)	Total HTH Addition	Cl_2 (ppm)	Remarks
	Liquid	Solids				
22 Nov 1972	--	--	1,587.0	1.587	--	--
27 Nov 1972	--	--			140	--
27 Nov 1972	--	--	254	1,841	800	--
29 Nov 1972	--	--			150	--
29 Nov 1972	--	--	720	2,561	1,900	--
30 Nov 1972	--	--			3,100	Dissolution of previous addition
30 Nov 1972	--	--	324	2,885	--	HTH added to toilet before pumpout/ filtration.
30 Nov 1972	--	--	--	--	560	After filtrate addition
30 Nov 1972	--	--	450	3,335	700	--
30 Nov 1972	46	4	2,885	--	--	57.7 g HTH/use
1 Dec 1972	7	2	450	--	--	50 HTH/use
5 Dec 1972	26	2	1.184	--	--	42.3 HTH/use
18 Dec 1972	55	4	713	--	--	12.1 HTH/use
22 Dec 1972	29	6	1,040	--	--	29.7 HTH/use
4 Jan 1973	37	8	737	--	--	16.4* HTH/use
11 Jan 1973	22	4	840	--	--	32.3 HTH/use
22 Jan 1973	17	1	2,089	--	--	116.2 HTH/use

---

*First batch in recirculating mode.

TABLE 12

ANALYSIS OF TREATMENT TANK SLUDGE
(8 Dec 1972)

$CaCl_2$ = Principal compound
Na = 1.5%
SO_4 = 0.45%
Si = 0.27%
Mn = 0.015%
Fe = 0.27%
Mg = 0.1%
Al = 0.38%
Sn = 0.021%
Cu = 0.1%
Zn = 0.29%
Ti = 0.025%

the wastewater resulted in a saturated solution with respect to calcium chloride. Consequently, crystallization was observed in the treatment tank. An analysis of the solids sample from the bottom of this tank confirmed calcium chloride as the principal constituent (Table 12).

At the conclusion of the extended test period, two water samples were taken for detailed analysis and evaluation. The first sample was analyzed for BOD, virus, and conventional inorganic properties (Table 13). As noted in Table 13, the system is saturated with respect to calcium chloride. Virus tests were negative. Although a high residual BOD concentration was observed, suspended solids were low and the water was concluded to be satisfactory for reuse as a flush media. The second water sample was submitted to the Utah Water Research Laboratory at Utah State University, under an independent research grant funded by Thiokol Corporation, for isolation and identification of those ingredients comprising the high residual BOD concentration. The results of these tests are presented in detail in a separate report (Adams, V. Dean & Middlebrooks, E. Joe, "Identification of Organic Compounds in a Closed-Loop Hypochlorite Wastewater Treatment System," Utah State University, Logan, Utah, May 1973) which is included in the Appendix. It was concluded that the material was a complex mixture consisting mainly of saturated chlorinated fatty acids, presumably a reaction product of lipids in feces, by free radical chlorination and chlorine addition.

During the early part of March, the waste treatment system (test Configuration IV) was installed in a closet which had dimensions identical to the closet on the Thiokol houseboat. The installation (Figure 23) simulated boat operation.

Operation of the system in the confined space disclosed no operational problems. The closet doors were kept closed during incineration and as much as possible during normal operation to detect odor or heat problems. During incineration periods (10 min of burner operation) the closet temperature did not rise over 15° to 20° F above ambient, indicating sufficient insulation. The combustion air is drawn from the closet interior which maintains an even closet temperature and gives odor-free incineration.

Usually the system had 20 to 25 liquid uses and 4 solid uses in each treated batch. The number of uses in each batch was very dependent upon the orientation given toilet users. A degree of user care is necessary to prevent excess use of flushwater.

An average of 1-1/2 lb of powdered HTH was added to each batch to oxidize organics and sanitize the solution. No odor problems were experienced; the recycle liquid remained clear, containing between 120 and 350 ppm Cl_2. Since the water does not remain in the bowl of the toilet, but immediately flows to a sewage hold tank, the high Cl_2 content of the flushwater has no objectional effects.

TABLE 13

HOUSEBOAT SYSTEM FLUSH LIQUID
(10 Oct 1972 to 23 Jan 1973)

Analysis	Results
Virus	No detectable virus present
Biochemical oxygen demand	2,125 ppm
Calcium	17,360 mg/l
Magnesium	182 mg/l
Sodium	12,000 mg/l
Potassium	945 mg/l
Copper	0.35 mg/l
Lead	5.36 mg/l
Zinc	2.18 mg/l
Iron	3.10 mg/l
Total organic nitrogen	2.50 mg/l
Albuminoid ammonia	0.13 mg/l
Free ammonia	0.00 mg/l
Nitrite (NO_2-N)	3.65 mg/l
Nitrate (NO_3-N)	4.20 mg/l
Carbonate	0.00 mg/l
Hydroxide	0.00 mg/l
Sulfate	705 mg/l
Chloride	46,500 mg/l
Total solids	89,620 mg/l
Phosphate (PO_4)	5.20 mg/l
Suspended solids	48.0 mg/l

Figure 23. Houseboat Waste Treatment System Installed in Closet

Testing was completed during April and system installation on board the Thiokol houseboat was initiated.

Field Testing

During April and May, the system was removed from the Thiokol/Wasatch test facility and installed on the Thiokol houseboat (Figures 24 and 1). Lake testing was originally scheduled for late May. However, Bear Lake, selected as the best site for testing the houseboat system, was unseasonably cold until mid-June. Photographs of the actual houseboat installation are shown in Figures 25 and 26, indicating the general location of the treatment system in the rear portion of the houseboat and a closeup view of the filter-incinerator, holding tank, and control panel. Figure 27 is a schematic diagram of the electrical system.

In May, the waste treatment system, installed on the houseboat, was charged with water and chemicals. The system was activated to check all operational modes, and plant personnel were encouraged to use the system. Two batches of sewage were processed before shipment to Bear Lake on 13 June.

To field test the system, Thiokol employees with their families and friends were invited to spend vacations, weekends, and holidays aboard the boat. The boat was furnished with six beds plus floor space for sleeping bags. Because of the high turnover of personnel using the boat, a local full-time operator was employed to pilot the craft, perform routine maintenance, and keep records. Four documents were used to aid monitoring system performance on board the houseboat.

1. Toilet Use Record.
2. Houseboat Waste Treatment System Usage Questionnaire.
3. Houseboat Waste Treatment System Log.
4. Boat Log.

Items (1) and (2) were voluntary data furnished by the users of the system; items (3) and (4) were log books maintained by the boat operator. Samples were obtained by each returning party for laboratory analysis.

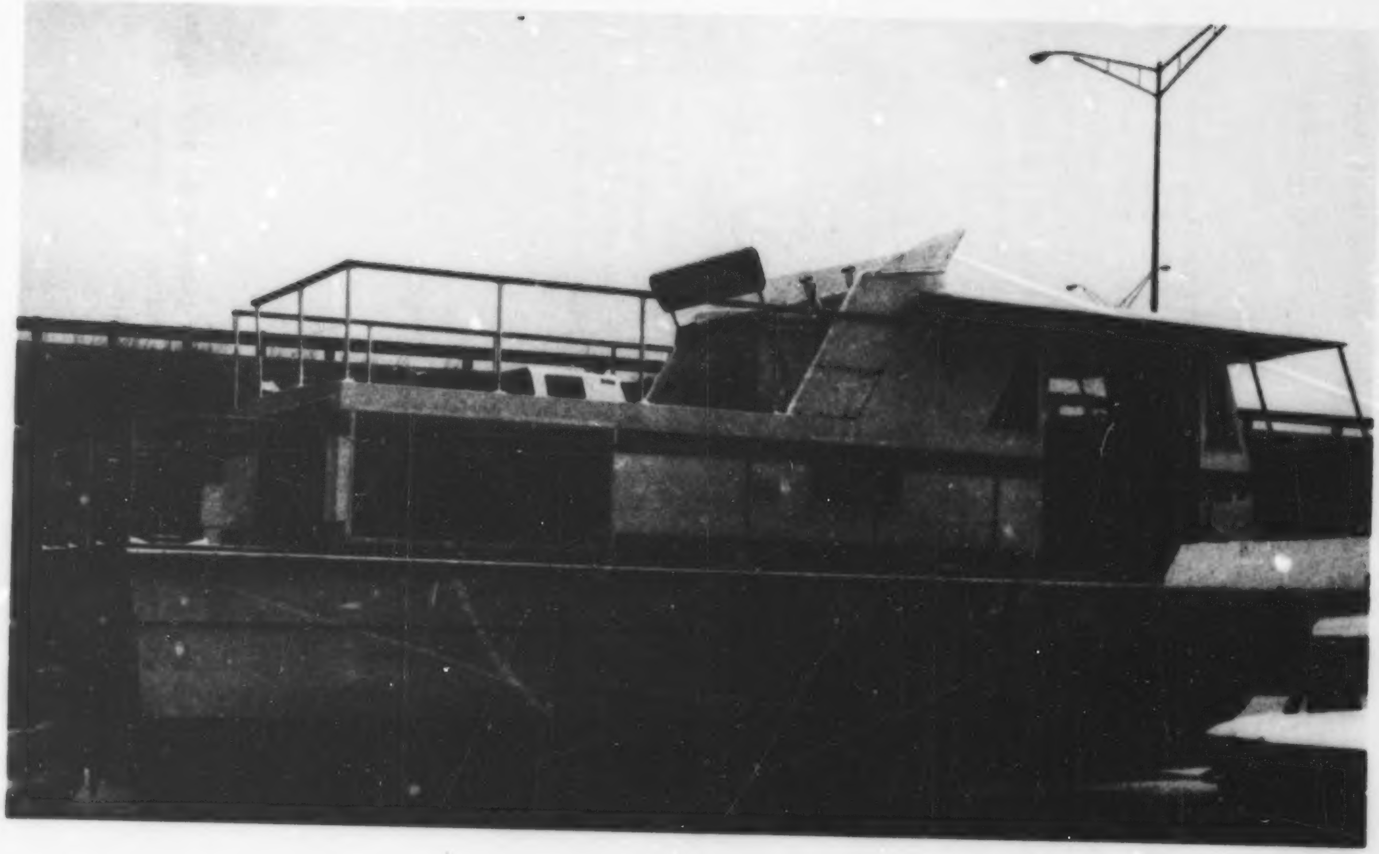

Figure 24. Thiokol Houseboat

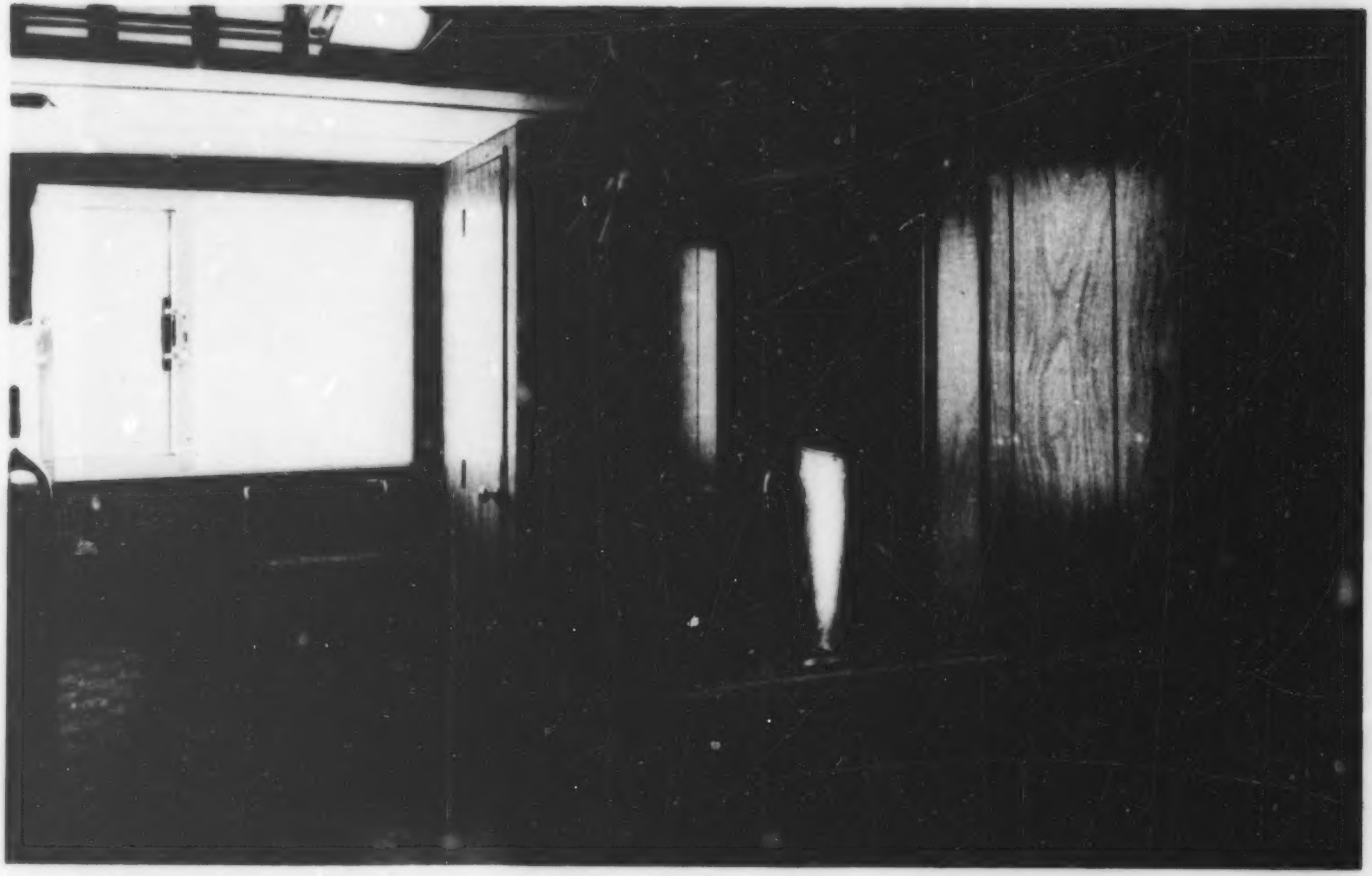

Figure 25. Thiokol Houseboat Waste Treatment System Installation

Figure 26. Houseboat Waste Treatment System Closeup

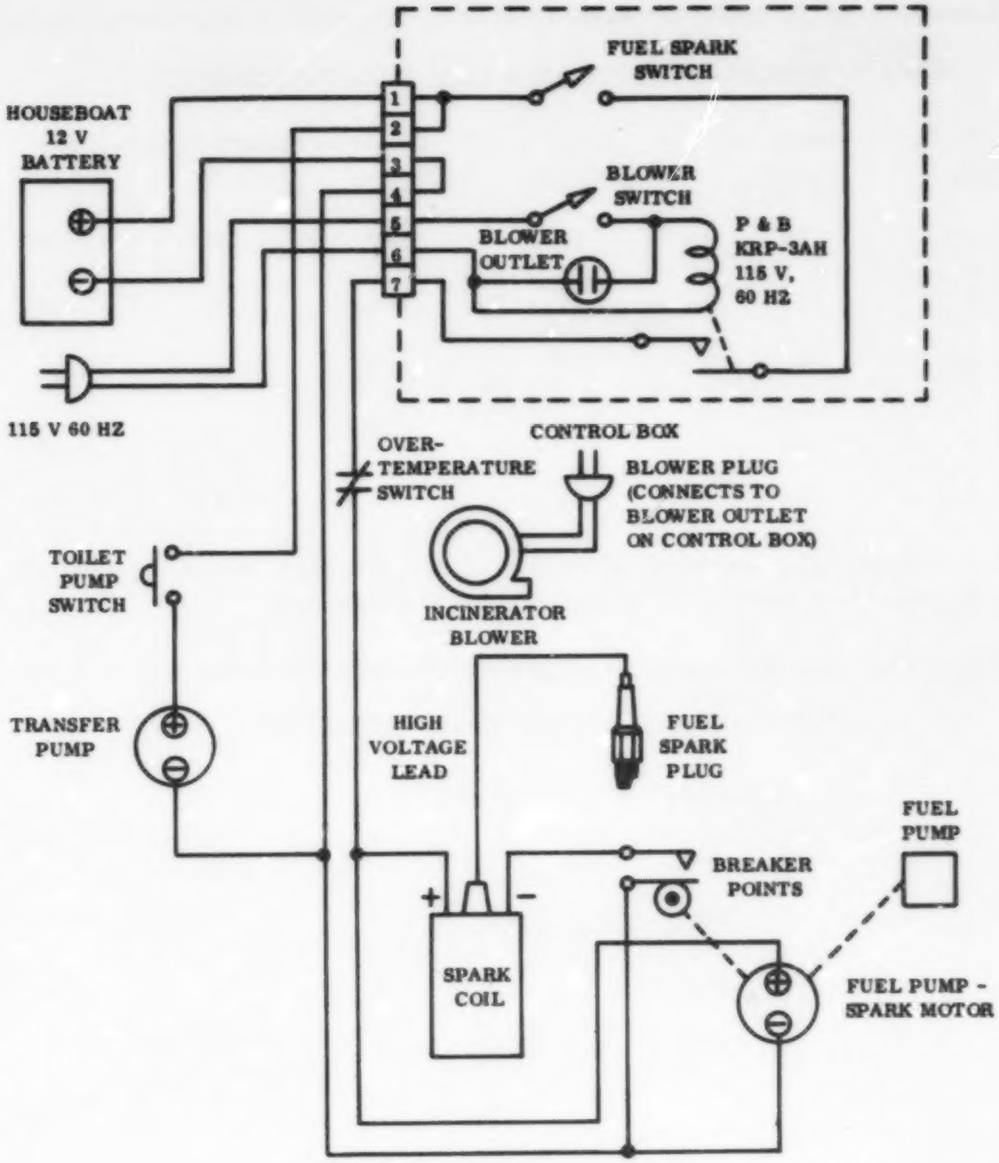
FUEL SPARK SWITCH
HOUSEBOAT 12 V BATTERY
1
2
3
4
5
6
7
BLOWER SWITCH
BLOWER OUTLET
P & B KRP-3AH 115 V, 60 HZ
115 V 60 HZ
CONTROL BOX
OVER-TEMPERATURE SWITCH
BLOWER PLUG (CONNECTS TO BLOWER OUTLET ON CONTROL BOX)
TOILET PUMP SWITCH
INCINERATOR BLOWER
TRANSFER PUMP
HIGH VOLTAGE LEAD
FUEL SPARK PLUG
FUEL PUMP
BREAKER POINTS
+
−
SPARK COIL
FUEL PUMP - SPARK MOTOR

Figure 27. Houseboat Waste Treatment System Electrical Schematic

A summary of the houseboat waste treatment system usage is presented below.

USAGE SUMMARY--HOUSEBOAT WASTE TREATMENT SYSTEM

Month	Operating Days	Total Visitors	Waste Treatment System Uses Liquid	Waste Treatment System Uses Solid	Waste Treatment System Uses Total
Jun	15	59	179	50	229
Jul	18	161	351	68	419
Aug	20	201	358	90	448
Sep	4	30	40	14	54
	57	451	928	222	1,150

It is estimated that one-third to one-half of the total visitors were daytime visitors, with the balance spending the night on board the boat.

HTH dosage over the entire test program averaged a little more than 1 lb per day.

HOUSEBOAT SYSTEM CHLORINE CONSUMPTION

Month	HTH Used (lb)
Jun	7-1/2
Jul	22
Aug	25
Sep	6
	60-1/2

The appearance of the recycled liquid varied from colorless to a light straw color during the test period. Only a few users of the system commented on the appearance of color of the flushwater, and only one stated that it was objectionable. Some negative comments were made concerning the poor flushing action of the toilet and the small holding tank capacity. It appears, however, that users of the system with previous experience with camping toilets had the least difficulty and objections.

Analyses of the treatment tank liquid are summarized in the following table.

TREATMENT TANK LIQUID ANALYSES

Date	BOD	Cl_2	Coliform	pH
15 Jun 1973	2,120	56	--	--
17 Jun 1973	3,050	247	None	--
23 Jun 1973	2,500	201	None	5.8
1 Jul 1973	6,700	720	None	--
7 Jul 1973	4,100	550	None	5.8
20 Jul 1973	3,450	237	None	5.4
26 Jul 1973	3,640	359	--	5.9
8 Aug 1973	2,920	161	--	6.4
9 Aug 1973	3,170	233	--	6.2
13 Aug 1973	4,780	276	--	5.6

A total of 55 responses to the questionnaire were received during the field test program.

HOUSEBOAT WASTE TREATMENT SYSTEM USAGE QUESTIONNAIRE

	Yes	No	
Have you used portable toilets previously?	30	25	
Did you experience difficulty flushing the houseboat toilet?	11	43	
Did you notice objectionable odors issuing from the toilet (not from the user)?	18	37	
Did you notice objectionable odors or smoke during the incineration cycle?	23	26	
How would you compare the houseboat system to other portable systems? (circle one)	Better 34	Same 3	Worse 0
If you were a boat owner, how much would you pay to have a system similar to the houseboat's installed on your boat?	$553 Avg (24 no comments)		

A "dry bowl" type toilet causes problems for some people. If toilet paper is folded and placed in the toilet before use, flushing problems usually are eliminated. In some cases, the objectionable odors issuing from the toilet were from chlorine, not sewage. The reaction to chlorine is often a matter of personal preference--some people define a slight chlorine odor as a "clean" smell. During the times sewage odors were detected, addition of extra chlorine eliminated the problem.

The odors noticed during incineration were apparent only on the top deck of the houseboat. No odors have been apparent inside the boat. Until the exhaust is up to about 500° F (first 3 to 4 min), a mild "wet paper" odor is noticeable.

Many of the questionnaire respondents didn't feel qualified to compare the houseboat system to other portable systems.

The following is a chronological summary of the operating problems encountered during the field demonstration program.

June--During late June, difficulty was experienced starting the incinerator. The problem was determined to be due to insufficient fuel supply caused by a low level in the boat's gasoline tanks. A supplemental electric fuel pump was added to supply fuel to the incinerator at all times. Another boat problem encountered was loss of the flush pump. The pump was not secured adequately, fell over, and the water ruined the dc motor.

Fourteen gallons of water were removed from the system on 27 June. There is some question as to whether the liquid accumulation was due to user input or from a leaky valve on the toilet.

Through 25 June, the toilet was emptied eight times and solids were incinerated three times. On 23 June, the burner would not fire due to a ruptured fuel pump. The toilet was emptied into the filter-incinerator several times before the burner was placed back into operation. A firing time of 30 min was necessary to burn off the excessive solids, compared to the 10 min normally required. The failure of the fuel pump diaphragm had not been experienced before and is thought to be due to a defective diaphragm.

July--The houseboat waste treatment system received heavy use during July, interrupted only by a brief period when the houseboat hull was damaged and the boat took on 1-1/2 ft of water. The partial swamping of the boat was caused by a depth indicator probe being loosened. The boat was tilted with the port side (where the waste treatment system is located) being considerably higher than starboard. Consequently, there was no change in liquid inventory in the waste treatment system. The boat was out of the water from 12 to 16 July for repairs and drying the interior.

1 July - The hose between the toilet and the toilet discharge pump apparently plugged and prevented complete solids removal from the toilet.

2 July - Filtration time was excessive on one day possibly because the preceding incineration had been inadequate. In general, overnight filtration (by gravity) had been adequate after the filter cloth was incinerated once. A new cloth seemed to give slow filtrations.

5 and 9 July - The filter cloth was changed. Inspection on 9 July showed the filter cloth had been cut with an excessive diameter--the resulting wrinkles failed rapidly.

6, 8, and 9 July - The problem of solids not transferring from the toilet continued. On the 9th the accumulated solids in the toilet were flushed out by adding several 5 gal washes of fresh water through the toilet. The solids were pumped to a separate container. The solids, with about 4 gal of system liquid, were disposed of on shore. Quantities of lettuce and other foodstuffs were observed floating on

top of the discharged solids, indicating the toilet was used as a receptacle for more than body wastes.

7 July - Additional HTH was added because of odor problems.

A problem was occasionally experienced with ignition of the F/I burner. A fuel pressure gage was installed before the fuel nozzle which indicated a lack of gasoline pressure to the burner when ignition would not occur (7/23 and 7/24).

The system inventory increase noted in June was not experienced during July; conversely on 25 July the tank level had dropped below the filtrate line allowing smoke to enter the passenger cabin during incineration. One gallon of water was added to maintain the proper level.

The incineration cycle was monitored on 26 July. A thermocouple in the exhaust stack gave the following readings:

HOUSEBOAT INCINERATION

Time After Starting Incineration	Exhaust Temperature (°F)
3 min	400
5 min	920
8 min	940
9 min	1,000
10 min	1,100
Fire off at 10 min	
15	560

The incinerator interior was inspected after cooldown; incineration was complete.

During the 26 July test, the 12 vdc line which supplied current to the fuel/spark assembly contacted the exhaust stack. The resulting short circuit destroyed much of the 12 v system wiring. The damaged wires were replaced and rerouted to prevent a recurrence.

August--On several occasions, solids plugged the transfer line from the toilet to the filter-incinerator. In addition, the flat bottom arrangement of the toilet

holding tank caused solids separation, bridging, and dewatering of the sewage. This condition required stirring and/or additional water to dislodge the solids. To correct this situation, the toilet was modified by making the toilet seat and upper section removable. The lower section, or holding tank, was provided with a dished bottom by laying in a molded epoxy-fiberglass section. Tests were conducted with simulated sewage, and showed that the new design was effective in providing positive drainage from the toilet.

On 9 August, the modified toilet was installed on the houseboat. At the same time the transfer line from the toilet to the filter-incinerator was rerouted to shorten the distance and eliminate unnecessary bends. A standard Monomatic macerating transfer pump was also installed in place of the hand-operated diaphragm pump in an effort to prevent line plugging.

Several days of operation with these modifications proved disappointing. Although no problems were encountered in transferring sewage, excessively long drain times were required in the filter-incinerator to produce a dense mat suitable for incineration. Believing this to be the result of shredding and particle size reduction, the macerator pump was removed and the diaphragm pump reinstalled in the waste treatment system compartment. For the remainder of the test program, through September, no further difficulty was reported in either transferring sewage or draining in the filter-incinerator. Generally, 10 to 15 strokes on the diaphragm pump was sufficient to transfer a full tank and as little as 23 min of filtration was observed.

Recurring reports of black smoke and strong odor from the filter-incinerator exhaust stack prompted a close examination of the system. Suspecting an improper air/fuel mixture, both the fuel supply system and air blower were dismantled and inspected. It was found that the blower functioned erratically and delivered less than its rated capacity. Inspection of the operating records indicated that the blower motor had probably been damaged by corrosion and dirt when one user of the system pumped an excessive quantity of liquid to the filter-incinerator, allowing it to back up into the blower. Replacing the blower motor eliminated the black smoke and the odor associated with incomplete combustion of the sewage solids. The Refrasil filter cloth was also examined and found to be in excellent condition, requiring no changes for the remainder of the test program.

In discussions with EPA representatives, the desirability of converting the houseboat filter-incinerator from a gasoline-fired system to a diesel fuel-fired system was reviewed. In developing the houseboat system, all applicable standards established by the U.S. Coast Guard for pleasure craft were complied with. However, Section 58.01-10 of Marine Engineering Regulations, CG-115, prohibits the use of gasoline-fired devices on commercial vessels. Therefore, in order to extend the applicability of this waste treatment system to passenger vessels, additional work was needed to demonstrate a diesel fuel-fired filter-incinerator. This effort could be accomplished without change in contract funding, but an extension of the period of technical performance was required. A formal Technical Change Proposal was submitted, requesting this extension, to the Negotiated Contracts Branch of the EPA. On 14 September, the test program on the lake was terminated and the houseboat returned to the Wasatch Division for removal of the waste treatment system.

Fuel Oil Tests

In October, the waste treatment system was removed from the houseboat and placed in a test facility at the Wasatch Division. The interior of the filter-incinerator was examined and showed evidence of corrosion and/or oxidation of the metal walls. The Refrasil filter, however, appeared to be intact with a coating of ash and charred residue.

Preliminary experiments were carried out to determine if the gasoline-fired burner could be operated with fuel oil. The existing fuel nozzle, air blower and ignition system were used with a high pressure fuel oil pump, available from a standard, domestic oil burner. Ignition was erratic requiring adjustment of the spark gap relative to the fuel jet. Steady burning was achieved, but poor combustion was evident by a trickle of fuel oil and a spray of oil droplets issuing from the combustion chamber pipe. It was concluded that this condition resulted from a poor combination of spray pattern, droplet size, chamber geometry and air mixing. With gasoline as the fuel, combustion is enhanced by the higher volatility which vaporizes the fuel and promotes rapid mixing with air. Fuel oil, on the other hand, requires mechanical action and a high degree of turbulence to form an aerosol suitable for stable ignition and combustion.

To achieve these conditions, a standard commercial oil burner (Nu-Way, Model 1002 FM) was mounted on the filter-incinerator with a modified hot gas inlet manifold.

The existing vertical downfiring gasoline parts were removed and the inlet hot gas duct blanked off. A new incinerator cover was fabricated from 1/8 in. thick 304 stainless steel. A 7 in. long standard oil burner draft tube was welded to the outer edge of the cover at a 45° angle to provide a hot gas duct and mounting flange for the burner (Figures 28 and 29). The unit was later modified with a 12 in. draft tube to provide greater clearance between the incinerator and the burner/blower.

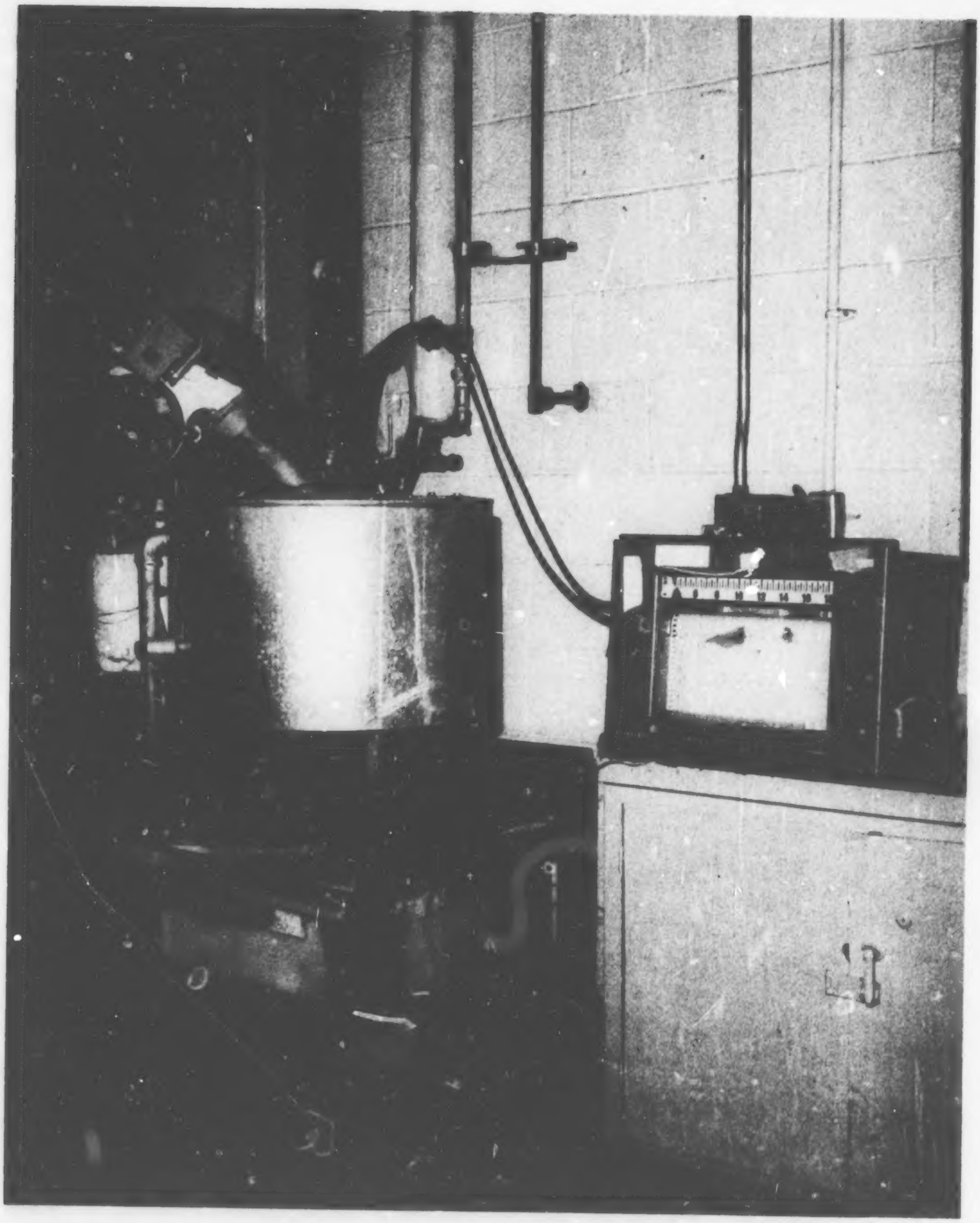

Figure 28. Hot Gas Duct and Mounting Flange, Right Three-Quarter View

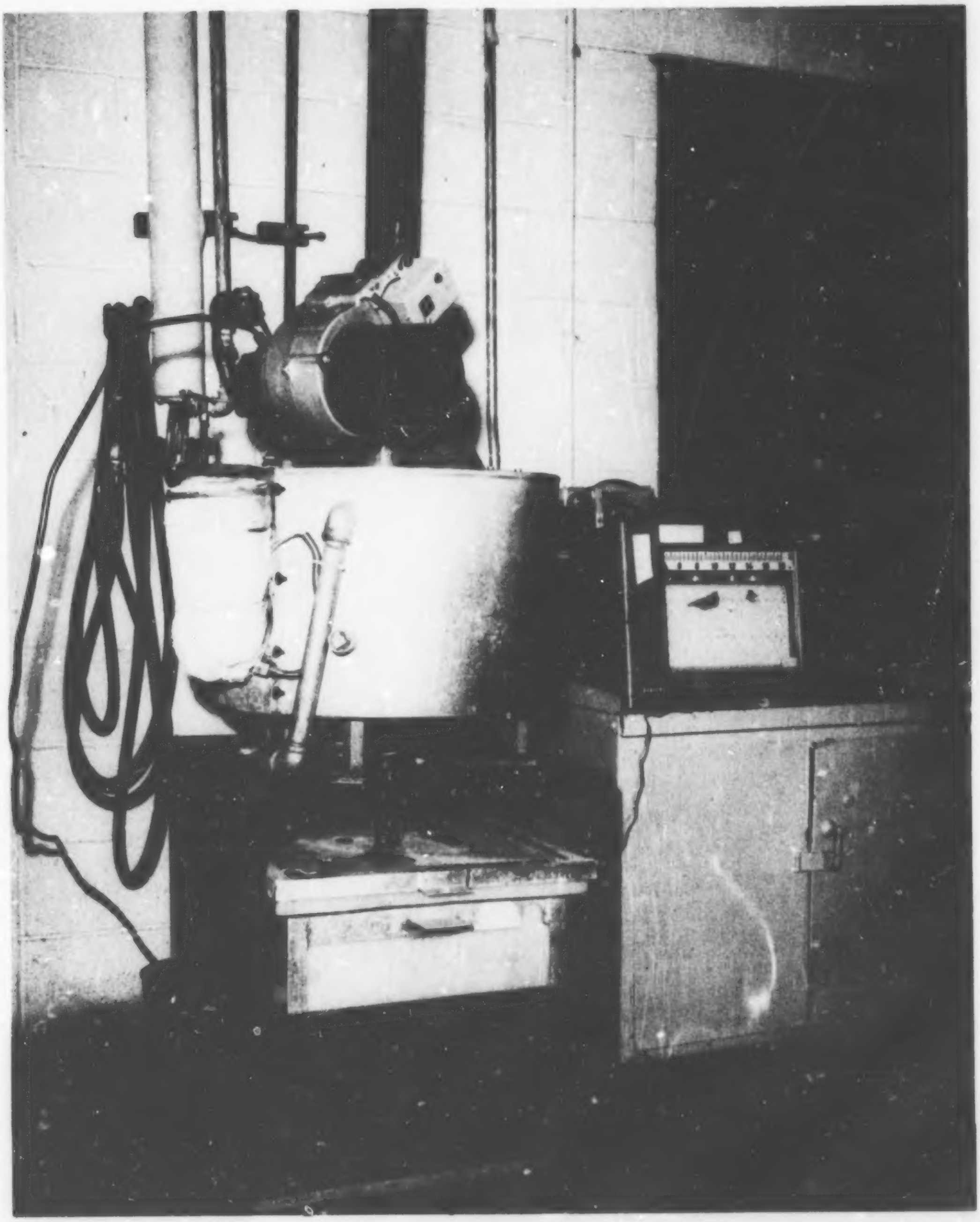

Figure 29. Hot Gas Duct and Mounting Flange, Left Three-Quarter View

In November, the unit was test fired under the following conditions:

		Test No. 1	Test No. 2	Test No. 3
1.	Draft tube length (in.)	7	12	12
2.	Fuel nozzle (gph/angle)	0.50/80W	0.65/80W	0.65/80W
3.	Calculated delivery rate (gph)	0.50	0.65	0.57
4.	Fire ring/flame retention	Fire ring	Flame ret	Fire ring
5.	Fuel pressure (psi)	100	100	100
6.	Bus bar	Clamped	Clamped	Soldered
7.	Equilibrium temp (°F)	--	--	1,400
8.	Firing time (min)	15	5	30
9.	Remarks	Slight roar; leaks fumes	--	Cover and discharge flue hot; slight roar; no leakage of fumes.

Test No. 3 showed excellent results and indicates only minor changes are required to achieve the desired 1,200° F incinerator temperature. This can be accomplished with a lower fuel rate by either throttling fuel pressure (Figure 30), or reducing the fuel nozzle orifice size. Reducing the orifice increases the risk of plugging the nozzle, as was encountered in Test No. 1. In all cases, no ignition failures were encountered during the tests. However, it is recommended that filter-incinerator exhaust stack diameter be increased from 3 in. to 5 in. to decrease back pressure and assure flame stability.

No tests were carried out with filtered sludge in the incinerator because of a lack of a suitable sewage source during the test period.

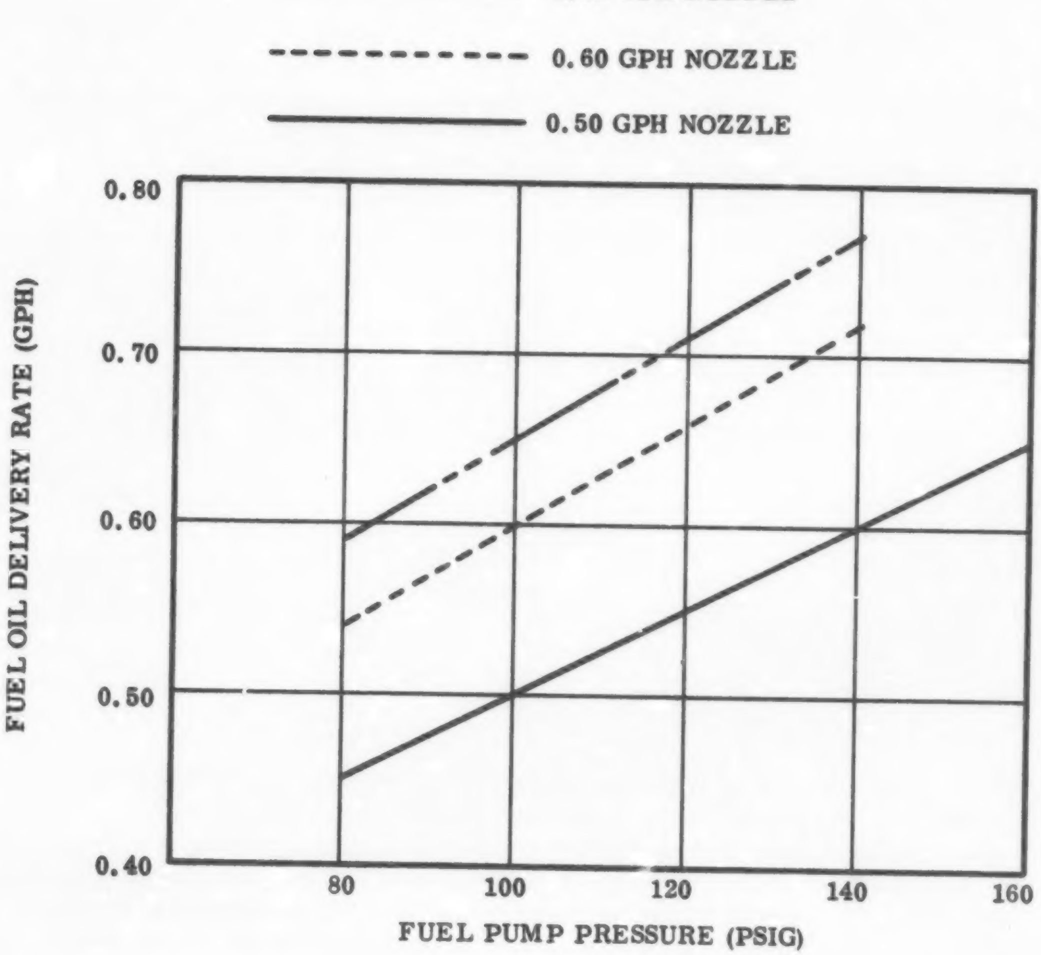

Figure 30. Fuel Oil Delivery Rate vs Fuel Pump Pressure for 0.50, 0.60, and 0.65 gph Nozzles

SECTION VI

SYSTEM ECONOMICS

A study was made to determine the production cost of the system tested on the houseboat. The estimate was based on a marine recirculating system with low flow (1 qt) toilet and houseboat type filter-incinerator capable of 15 gpd or 60 flushes/day. The estimated selling price of each unit, assuming 20 units per year production rate, is $2,760. This price is considerably higher than the $553 average that the users of the houseboat indicated that they would be willing to pay. The selling price, however, is largely dependent upon volume of production, and a 50% price reduction could readily be achieved in mass production.

Installation costs could vary considerably, depending on the craft design. There are a number of potential installation locations on most vessels. The installation location decision would be based not only on costs, but also on simplifying operation and preserving the esthetics of the entire vessel. Tabulated below is an estimate of the installation costs based on placing the system in a closet adjacent to the head, with minimum piping runs and incinerator exhaust ducting.

COST OF SYSTEM INSTALLATION

Item	Cost
Boat modification labor	$21.00
Boat modification material	10.00
Piping installation	14.00
System assembly checkout	14.00
Electrical labor	7.00
Electrical material	5.00
Total	$71.00

Based on labor at $7.00/hr

The following table summarizes the operating costs of the system.

*COST OF SYSTEM OPERATION

Item		Cost ($)
Electrical power at $0.05/kwh		
Fuel pump/spark motor	0.025 kwh	
Blower	0.126 kwh	
Flush pump	0.002 kwh	
Exhaust fan	0.104 kwh	
	0.257 kwh	0.02
Gasoline (1/2 gal)		0.30
HTH (1 lb)		1.00
Filter media		0.05
	TOTAL	1.37

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*Based on one cycle of 20 to 30 toilet uses or transfer of one 6 gal batch to the filter-incinerator.

SECTION VII

COAST GUARD REVIEW

A portion of the work that was to be included in Phase I of the "Devices for Onboard Treatment of Wastes from Vessels" contract was to supply sufficient information to the U.S. Coast Guard to enable them to issue a written opinion. Communications began in August of 1971 and a preliminary technical package was sent to Commander Albert Stirling at the Washington, D.C., office.

On 24 Mar 1972, Chief William M. Robinson, who was with the local Coast Guard, visited the Wasatch Division and viewed the houseboat prototype. Chief Robinson indicated the use of gasoline as a fuel was acceptable on a privately operated boat, but that diesel fuel would be required for a commercial vessel.

On 18 Aug 1972, a complete waste treatment system design package was sent to Commander Stirling with a duplicate directed to Mr. L. McCarthy of the EPA.

On 24 Aug 1972, Commander Sipes informed us he had received the design package, that he was handling duties previously performed by Commander Stirling, and that the package was sent to the Regulation Drafting Section for review.

On 28 Aug 1972, Commander Schumacher of the Regulation Drafting Section informed us the review could take up to 1 month.

On 4 Oct 1972, Richard Landin of the Marine Engineering Branch informed us it would be several weeks before an evaluation could be made of our system.

In a letter dated 27 Oct 1972, Captain M. B. Lemly, Chief, Merchant Marine Technical Division, advised Thiokol Corporation that the sewage treatment meets applicable Coast Guard safety requirements with the exception of the gasoline preheater in the incineration chamber. This letter confirmed that gasoline-fired devices were prohibited on commercial passenger vessels.

APPENDIX I

SUMMARY OF FILTER-INCINERATOR TESTS

SUMMARY OF FILTER-INCINERATOR TESTS

Test	Test Configuration	Results SS In (mg/l)	SS Out (mg/l)	Gal /Sq Ft	Filt Time (min)	No. of Cycles	Remarks
Thiokol IR & D Tests, Single Element							
	5 Polypropylene Bag	425	60	33	80	1	
GF-1	C1554-48 Refrasil, 1 Layer	284	120	8	12	1	
GF-2	C1554-48 Refrasil, 1 Layer	284	137	6	9	2	
GF-3	C100-48 Refrasil, 1 Layer	364	110	10	10	1	
GF-4	C100-48 Refrasil, 1 Layer	364	118	10	11.5	2	
GF-5	C100-48 Refrasil, 1 Layer	212	97	5	5	3	
GF-6	C100-48 Refrasil, 1 Layer	212	112	7.5	8	4	
GF-7	C100-48 Refrasil, 1 Layer	435	219	7.5	7.5	5	Holes cut in cloth by clamps
GF-8	C100-48 Refrasil, 1 Layer	435	239	8	9	6	
GF-9	C100-48 Refrasil, 2 Layers	675	60	8	3	1	
GF-10	C100-48 Refrasil, 2 Layers	675	90	7.5	7	2	
GF-11	C100-48 Refrasil, 2 Layers	--	--	6	5.5	3	
GF-12	C100-48 Refrasil, 2 Layers	352	108	7	5	4	
GF-13	C100-48 Refrasil, 2 Layers	352	90	5.8	8	5	Cloth in excellent condition
GF-14	C1554-48 Refrasil, 2 Layers	445	153	10.4	5	1	
GF-15	C1554-48 Refrasil, 2 Layers	780	103	30	25.5	2	
GF-16	C1554-48 Refrasil, 2 Layers	126	84	12	8	3	
GF-17	C1554-48 Refrasil, 2 Layers	126	55	35	34	4	
GF-18	C1554-48 Refrasil, 2 Layers	126	67	13	9	5	
GF-19	C1554-48 Refrasil, 2 Layers	71	80	10	8.3	6	
GF-20	C1554-48 Refrasil, 2 Layers	71	69	13	9.2	7	Cloth in excellent condition
GF-21	C1554-48 Refrasil, 2 Layers	(water)		20	3.3	8	
GF-22	C1554-48 Refrasil, 2 Layers	(water)		20	3.3	9	
GF-23	C1554-48 Refrasil, 2 Layers	(water)		20	3.3	10	
GF-24	C1554-48 Refrasil, 2 Layers	(water)		20	3.3	11	

SUMMARY OF FILTER-INCINERATOR TESTS (Cont)

Test	Test Configuration	Results					Remarks
		SS In (mg/l)	SS Out (mg/l)	Gal /Sq Ft	Filt Time (min)	No. of Cycles	
Thiokol IR & D Tests, Single Element (Cont)							
GF-25	C1554-48 Refrasil, 2 Layers	630	218	10	8.3	12	Slight cloth damage under clamp
GF-26	L-70-791 16 oz Novatex, 1 Ply	623	222	6	4.2	1	
GF-27	L-70-791 16 oz Novatex, 1 Ply			3	3.2	2	
GF-28	L-70-791 16 oz Novatex, 1 Ply	--	--	2.5	3	3	
GF-29	L-70-652 24 oz Novatex, 1 Ply	--	--	5.75	4.6	1	Incineration temp decreased to 1,200°F because of cloth limitation
GF-30	L-70-652 24 oz Novatex, 1 Ply	--	--	16	7.1	2	
GF-31	L-70-652 24 oz Novatex, 1 Ply	--	--	7	5	3	
GF-32	L-70-652 24 oz Novatex, 1 Ply	--	--	34	15.8	4	Applied pressure inc to 15 psig
GF-33	L-70-652 24 oz Novatex, 1 Ply	--	--	35	12.9	5	
Coast Guard, Single Element							
GF-34	Sintered Stainless Steel Beads	--	--	2	3	1	ΔP across filter = 15 psi. Throughput excessively low
GF-35	S/570/38/9108 Quartz Cloth, 1 Ply	383	177	28	11	1	ΔP = 15 psi
GF-36	S/570/38/9108 Quartz Cloth, 1 Ply	383	177	24	8.8	2	ΔP = 15 psi
GF-37	S/570/38/9108 Quartz Cloth, 2 Ply	478	138	25	8.9	1	
GF-38	S/570/38/9108 Quartz Cloth, 2 Ply	420	134	25	9.6	2	
GF-39	S/570/38/9108 Quartz Cloth, 2 Ply	420	135	18	4.8	3	
GF-40	S/570/38/9108 Quartz Cloth, 2 Ply	7,630	313	4.25	4.5	4	
GF-41	S/570/38/9108 Quartz Cloth, 2 Ply	393	285	20	11	5	Salted sewage, 3% salt
GF-42	S/570/38/9108 Quartz Cloth, 2 Ply	393	172	26	6	6	Salted sewage, 3% salt

---

*Manufacturer's Designation.

SUMMARY OF FILTER-INCINERATOR TESTS (Cont)

Test	Test Configuration	SS In (mg/l)	SS Out (mg/l)	Gal /Sq Ft	Filt Time (min)	No. of Cycles	Remarks
		Results					
Coast Guard, Single Element (Cont)							
PPF-14	Fused Al_2O_3 Cylinder FAO No. 54, 3 in. OD, 2 in. ID, 12 in. L	330	148	18.5	15	1	Filter test only, H_2O, backflush not effective
PPF-15	Fused Al_2O_3 Cylinder FAO No. 54, 3 in. OD, 2 in. ID, 12 in. L	588	163	16.5	15	1	Salted sewage, 3% salt, incineration test conducted
PPF-16	Fused Al_2O_3 Cylinder FAO No. 54, 3 in. OD, 2 in. ID, 12 in. L	588	118	29.5	15	2	Salted sewage, 3% salt. Filter backflushed with H_2O three times during filtration. Incineration test conducted
PPF-17	Fused Al_2O_3 Cylinder FAO No. 54, 3 in. OD, 2 in. ID, 12 in. L	177	148	57	20	3	3% salt, $\Delta P = 4$ psi
PPF-18	Fused Al_2O_3 Cylinder FAO No. 54, 3 in. OD, 2 in. ID, 12 in. L	177	128	25	9	4	3% salt, $\Delta P = 2$ psi
PPF-19	Fused Al_2O_3 Cylinder FAO No. 54, 3 in. OD, 2 in. ID, 12 in. L	177	101	25	7	5	3% salt, $\Delta P = 2$ psi
PPF-20	Fused Al_2O_3 Cylinder FAO No. 54, 3 in. OD, 2 in. ID, 12 in. L	403	186	25	9	6	3% salt, $\Delta P = 2$ psi
PPF-21	Fused Al_2O_3 Cylinder FAO No. 54, 3 in. OD, 2 in. ID, 12 in. L	403	184	6.5	4.5	7	3% salt, $\Delta P = 5\text{-}10$ psi. Filter appeared plugged. Filter was cracked
PPF-22	Fused Al_2O_3 Cylinder FAO No. 80, 3 in. OD, 2 in. ID, 12 in. L	406	149	7.5	5	1	3% salt. Backwash ineffective for throughput increase. Slow heatup and cooldown to avoid thermal shock. Element cracked. Conclusion: can't use fused Al_2O_3 elements. Will try SiC elements
PPF-23	Fused Al_2O_3 Cylinder FAO No. 80, 3 in. OD, 2 in. ID, 12 in. L	406	206	3.5	7.5	2	3% salt. Backwash ineffective for throughput increase. Slow heatup and cooldown to avoid thermal shock. Element cracked. Conclusion: can't use fused Al_2O_3 elements. Will try SiC elements

SUMMARY OF FILTER-INCINERATOR TESTS (Cont)

Test	Test Configuration	SS In (mg/l)	SS Out (mg/l)	Gal / Sq Ft	Filt Time (min)	No. of Cycles	Filt ΔP (psi)	Salt Used	Remarks
		Results							
Coast Guard, Single Element (Cont)									
GF-43	4 in. D x 1/2 in. Thick Fiberfrax Long Staple Coarse Felt	760	150	10	--	1	10	--	Filtration only. 4 in. diameter test leaf
GF-44	C1554-48 Refrasil, 1 Ply	--	--	4	2	1	--	--	Run made simply to obtain filtrate sample
GF-45	B 2-1/2 Ref Tube, 4 in. D Leaf Test, 1 Ply	760	156	5	3	1	5	--	Filtration test only
GF-46	B-1570 Refrasil Fabbat	760	176	5	1	1	5	--	Filter test, 4 in. diameter test leaf
GF-47	C1554-48 Refrasil, 3 Ply	760	70	6	10	1	6	--	
GF-48	C1554-48 Refrasil, 3 Ply	526	80	6	8	2	7	--	
GF-50	FE-1021-X6 Fluid Dynamics Cylinder	290	136	3.3	2.4	1	8	--	15 micron porosity, 2 backwashes
GF-51	B 2-1/2 Ref Tube, 2-3/4 in. D x 12 in. L, 1 Ply	170	85	28	9	1	5	--	
GF-52	B 2-1/2 Ref Tube, 2-3/4 in. D x 12 in. L, 1 Ply	170	76	28	13.3	2	5	--	
GF-53	B 2-1/2 Ref Tube, 2-3/4 in. D x 12 in. L, 1 Ply	660	193	11	6.6	3	5	--	
GF-54	B 2-1/2 Ref Tube, 2-3/4 in. D x 12 in. L, 1 Ply	660	162	11	4	4	5	--	
GF-55	B 2-1/2 Ref Tube, 2-3/4 in. D x 12 in. L, 1 Ply	660	148	28	8	5	5	--	
GF-56	B 2-1/2 Ref Tube, 2-3/4 in. D x 12 in. L, 1 Ply	206	67	6.3	8.3	6	5	--	1 lb HTH per 50 gal. sewage (Floc 3678 SS)
GF-57	B 2-1/2 Ref Tube, 2-3/4 in. D x 12 in. L, 1 Ply	206	150	5.6	8.3	7	4	--	1 lb HTH per 50 gal. sewage (Floc 3678 SS)
GF-58	FE-1021-X6 Fluid Dynamics Cylinder	188	214	1.7	3.3	2	10	--	15 micron porosity, 1 backwash
GF-59	C100-48, 2 Ply Refrasil	295	84	4	4	1	7-9	Sea	Cloth cemented to support with Sauereisen No. 65. Cloth broke adjacent to cement during incineration. Filtered Hydrasieve underflow. Raw sewage SS = 720
GF-60	B 2-1/2 Refrasil, 2 Ply	718	120	5.5	5	1	8	Sea	Hydrasieve underflow. 1,100°F gas inlet.
GF-61	B 2-1/2 Refrasil, 2 Ply	718	99	10	15	2	10	Sea	Hydrasieve underflow. 1,100°F gas inlet. Static plus backwash
GF-62	B 2-1/2 Refrasil, 2 Ply	718	104	10	10	3	8	Sea	Hydrasieve underflow. 1,200°F gas inlet. 1 backwash
GF-63	B 2-1/2 Refrasil, 2 Ply	718	72	8.3	10	4	8	Sea	Hydrasieve underflow. 1,200°F gas inlet. 1 backwash

SUMMARY OF FILTER-INCINERATOR TESTS (Cont)

Test	Test Configuration	Results SS In (mg/l)	SS Out (mg/l)	Gal / Sq Ft	Filt Time (min)	No. of Cycles	Filt ΔP (psi)	Salt Used	Remarks
Coast Guard, Single Element (Cont)									
GF-64	B 2-1/2 Refrasil, 2 Ply	718	61	7.6	10	5	8	Sea	Hydrasieve underflow. 1,200°F gas inlet. 1 backwash
GF-65	B 2-1/2 Refrasil, 2 Ply	--	111	15.3	10	6	8	Sea	Hydrasieve underflow. 1,200°F gas inlet. No backwash
GF-66	B 2-1/2 Refrasil, 2 Ply	190	61	12.5	16.7	7	8	Sea	Hydrasieve underflow. 1,200°F gas inlet. 2 backwashes
GF-67	B 2-1/2 Refrasil, 2 Ply	190	69	34*	21.7	8	8	Sea	Hydrasieve underflow. 1,200°F gas inlet. 1 backwash
GF-68	L-70-652 Novatex, 24 oz, 2 Ply	262	146	25*	16.7	1	8	Sea	Hydrasieve underflow. 1,000°F gas inlet. 1 backwash
GF-69	L-70-652 Novatex, 24 oz, 2 Ply	262	86	25*	10	2	5-9	Sea	Hydrasieve underflow. 1,000°F gas inlet. No backwash
GF-70	L-70-652 Novatex, 24 oz, 2 Ply	262	140	40*	16.2	3	5	Sea	Hydrasieve underflow. 1,050°F gas inlet. No backwash
GF-71	L-70-652 Novatex, 24 oz, 2 Ply	245	212	38*	15	4	5	Sea	Hydrasieve underflow. 1,150°F gas inlet. No backwash
GF-72	L-70-652 Novatex, 24 oz, 2 Ply	305	89	18	20	5	4-10	NaCl	Raw sewage. 1,050°F gas inlet
GF-73	L-70-652 Novatex, 24 oz, 2 Ply	305	87	27	10	6	8-10	NaCl	Raw sewage. 1,100°F gas inlet
GF-74	L-70-652 Novatex, 24 oz, 2 Ply	305	99	20	15.7	7	10	NaCl	Raw sewage. 1,100°F gas inlet
GF-75	L-70-652 Novatex, 24 oz, 2 Ply	305	56	14	16.7	8	10	NaCl	Raw sewage. 1,100°F gas inlet
GF-76	L-70-652 Novatex, 24 oz, 2 Ply	490	107	28	18.4	9	10	NaCl	Raw sewage. 1,150°F gas inlet. 3% salt
GF-77	L-70-652 Novatex, 24 oz, 2 Ply	490	136	20	16.7	10	10	NaCl	Raw sewage. 1,125°F gas inlet. 3% salt
GF-78	L-70-652 Novatex, 24 oz, 2 Ply	490	113	30*	12.5	11	10	NaCl	Raw sewage. 1,125°F gas inlet. 3% salt
GF-79	L-70-652 Novatex, 24 oz, 2 Ply	272	196	16.5	5.3	12	10	NaCl	Raw sewage. 1,100°F gas inlet. 3% salt
GF-80	FAO No. 50, 3 in. OD x 2 in. ID x 12 in. L	190	138	20.7	6	1	7	--	Raw sewage. 1,175°F gas inlet.
GF-81	FAO No. 50, 3 in. OD x 2 in. ID x 12 in. L	190	--	27.4	17.8	2	8	--	Raw sewage. 1,175°F gas inlet.
GF-82	FAO No. 50, 3 in. OD x 2 in. ID x 12 in. L	190	132	19.8	11.6	3	8	--	Raw sewage. 1,175°F gas inlet.

---

*Ran out of sewage. Filter not plugged.

SUMMARY OF FILTER-INCINERATOR TESTS (Cont)

Test	Test Configuration	Results							Remarks
		SS In (mg/l)	SS Out (mg/l)	Gal / Sq Ft	Filt Time (min)	No. of Cycles	Filt ΔP (psi)	End-of-Run Gas Temp (°F)	
EPA Houseboat, Multiple Cycle Tests									
GF-83	Refrasil B 2-1/2 Braid, 2 Ply	878	38	6.2	5.8	1	10	1,040	
GF-84	Refrasil B 2-1/2 Braid, 2 Ply	878	45	4.9	6.7	2	10	1,000	
GF-85	Refrasil B 2-1/2 Braid, 2 Ply	878	58	4.9	6.7	3	10	1,020	
GF-86	Refrasil B 2-1/2 Braid, 2 Ply	270	36	5.2	8.3	4	10	1,075	
GF-87	Refrasil B 2-1/2 Braid, 2 Ply	270	13	5.9	10	5	10	1,075	
GF-88	Refrasil B 2-1/2 Braid, 2 Ply	270	32	6.2	10	6	10	1,080	
GF-89	Refrasil B 2-1/2 Braid, 2 Ply	270	286	5.9	10	7	10	1,080	
GF-90	Refrasil B 2-1/2 Braid, 2 Ply	270	42	5.9	10	8	10	990	
GF-91	Refrasil B 2-1/2 Braid, 2 Ply	460	4	4.2	8.3	9	10	1,000	
GF-92	Refrasil B 2-1/2 Braid, 2 Ply	460	12	4.9	8.3	10	10	1,100	
GF-93	Refrasil B 2-1/2 Braid, 2 Ply	460	2.5	4.6	8.3	11	10	1,080	
GF-94	Refrasil B 2-1/2 Braid, 2 Ply	460	52	14.6	11.7	12	10	1,080	
GF-95	Refrasil B 2-1/2 Braid, 2 Ply	460	302	13.9	11.7	13	10	1,080	
GF-96	Refrasil B 2-1/2 Braid, 2 Ply	460	32	13.2	11.7	14	10	1,075	
GF-97	Refrasil B 2-1/2 Braid, 2 Ply	460	30	12.9	11.7	15	10	1,080	
GF-98	Refrasil B 2-1/2 Braid, 2 Ply	485	168	3.1	10.4	16	10	1,080	
GF-99	Refrasil B 2-1/2 Braid, 2 Ply	485	46	3.5	10.8	17	10	1,080	
GF-100	Refrasil B 2-1/2 Braid, 2 Ply	485	22	3.8	13.3	18	10	1,050	
GF-101	Refrasil B 2-1/2 Braid, 2 Ply	485	18	3.7	10	19	10	1,050	
GF-102	Refrasil B 2-1/2 Braid, 2 Ply	485	12	3.5	10	20	8	1,050	
GF-103	Refrasil B 2-1/2 Braid, 2 Ply	485	17	3.5	10	21	--	1,050	
GF-104	Refrasil B 2-1/2 Braid, 2 Ply	485	29	4.2	10	22	--	1,050	
GF-105	Refrasil B 2-1/2 Braid, 2 Ply	485	16	3.5	10	23	8	1,060	
GF-106	Refrasil B 2-1/2 Braid, 2 Ply	229	10	4.2	11.7	24	--	1,100	
GF-107	Refrasil B 2-1/2 Braid, 2 Ply	229	8	3.1	10	25	8	1,090	

SUMMARY OF FILTER-INCINERATOR TESTS (Cont)

Test	Test Configuration	Results SS In (mg/l)	SS Out (mg/l)	Gal / Sq Ft	Filt Time (min)	No. of Cycles	Filt ∆P (psi)	End-of-Run Gas Temp (°F)	Remarks
EPA Houseboat, Multiple Cycle Tests									
GF-108	Refrasil B 2-1/2 Braid, 2 Ply	229	15	4.2	10.8	26	8	1,100	
GF-109	Refrasil B 2-1/2 Braid, 2 Ply	229	16	5.2	10.8	27	8	--	
GF-110	Refrasil B 2-1/2 Braid, 2 Ply	229	16	5.2	10.8	28	8	1,060	
GF-111	Refrasil B 2-1/2 Braid, 2 Ply	229	20	4.2	10.8	29	8	1,000	
GF-112	Refrasil B 2-1/2 Braid, 2 Ply	229	22	4.5	10.8	30	8	1,020	
GF-113	Refrasil B 2-1/2 Braid, 2 Ply	282	8.5	3.8	10	31	10	1,050	
GF-114	Refrasil B 2-1/2 Braid, 2 Ply	282	8	5.5	10	32	10	1,050	
GF-115	Refrasil B 2-1/2 Braid, 2 Ply	282	176	4.5	10	33	10	1,050	
GF-116	Refrasil B 2-1/2 Braid, 2 Ply	262	26	4.9	10	34	10	1,055	
GF-117	Refrasil B 2-1/2 Braid, 2 Ply	282	68	4.2	10	35	10	1,055	
GF-118	Refrasil B 2-1/2 Braid, 2 Ply	282	45	4.5	10	36	10	1,055	
GF-119	Refrasil B 2-1/2 Braid, 2 Ply	282	26	3.8	10	37	--	1,050	
GF-120	Refrasil B 2-1/2 Braid, 2 Ply	282	33	4.2	10	38	--	1,050	
GF-121	Refrasil B 2-1/2 Braid, 2 Ply	282	10	3.8	10	39	10	1,100	
GF-122	Refrasil B 2-1/2 Braid, 2 Ply	282	4	3.1	10	40	8	1,100	
GF-123	WRP-X-AQ Felt								SiO_2-Al_2O_3 refractory felt, second cycle. No test, filter failed
GF-124	Stainless Steel Cloth (Karma yarn 1/1 basket weave)								Filter ineffective
GF-125	Zirconia Cloth								Filter ineffective

SUMMARY OF FILTER-INCINERATOR TESTS (Cont)

		Results							
Test	Test Configuration	SS In (mg/l)	SS Out (mg/l)	Gal / Sq Ft	Filt Time (min)	No. of Cycles	Filt ΔP (psi)	End-of-Run Gas Temp (°F)	Remarks
EPA Houseboat, Multiple Cycle Tests									
GF-126	L-70-652 Novatex, 24 oz, 2 Ply	300	89	9	10	1	10	1,050	
GF-127	L-70-652 Novatex, 24 oz, 2 Ply	300	196	12.5	5.8	2	10	1,040	
GF-128	L-70-652 Novatex, 24 oz, 2 Ply	300	98	5	8.3	3	10	1,050	
GF-129	L-70-652 Novatex, 24 oz, 2 Ply	300	71	5.8	10	4	10	1,050	
GF-130	L-70-652 Novatex, 24 oz, 2 Ply	300	--	4	6.7	5	8	1,050	
GF-131	L-70-652 Novatex, 24 oz, 2 Ply	300	32	3.5	10	6	8	1,040	
GF-132	L-70-652 Novatex, 24 oz, 2 Ply	300	41	3.3	8.3	7	8	1,040	

APPENDIX II

IDENTIFICATION OF ORGANIC COMPOUNDS IN A CLOSED-LOOP HYPOCHLORITE WASTEWATER TREATMENT SYSTEM

by

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May, 1973

TABLE OF CONTENTS

Page

INTRODUCTION 92

DESCRIPTION OF PROCESS 92

PROCEDURES 94

RESULTS AND DISCUSSION 94

  Carbon Analyses 94
  Ether and Chloroform Extractions 96
  Alcoholic Silver Nitrate Reaction 103
  Deuterium Exchange Reaction 104

CONCLUSIONS 105

RECOMMENDATIONS FOR ADDITIONAL STUDIES . . . 110

REFERENCES 113

ADDENDUM to Appendix II 114

LIST OF FIGURES

Figure **Page**

1 Small Pleasure Boat System Schematic 93

2 Infrared Spectrum T-UWRL No. 1 97

3 Nuclear Magnetic Resonance Spectrum T-UWRL No. 1 . 98

4 Nuclear Magnetic Resonance Spectrum T-UWRL No. 2 . 101

5 Nuclear Magnetic Resonance Spectrum T-UWRL No. 3 . 102

6 Nuclear Magnetic Resonance Spectrum T-UWRL No. 3a . 106

7 Nuclear Magnetic Resonance Spectrum T-UWRL No. 3a + D_2O 107

8 Nuclear Magnetic Resonance Spectrum T-UWRL No. 6 . 108

9 Nuclear Magnetic Resonance Spectrum T-UWRL No. 6 + H_2O 109

LIST OF TABLES

Table **Page**

1 Distribution of carbon concentration in the treatment facility effluent 95

2 Identification of various peaks in the infrared and nuclear magnetic resonance spectra of Figures 2 and 3 99

3 Approach to identifying components of highly chlorinated wastewater treatment plant effluents 112

INTRODUCTION

The most significant problem occurring in a recycled effluent process utilizing physical treatment in conjunction with a catalyzed hypochlorite generating wastewater treatment process is the accumulation of organic compounds in the recycled effluent. Although these effluents are discharged to the environment infrequently, care must be exercised to ensure that unexpected consequences are not produced. However, the greatest concern for these accumulated compounds results in the reuse of the effluent for flushing operations. If the chlorine residual were to be exhausted before the effluent were returned to the treatment plant, biological activity and discoloration could occur. The discoloration is of aesthetic concern and most users of the process would insist upon an odorless and clear flush water.

To prevent the recurrence of this type of difficulty in the process, it was first necessary to identify these compounds. The results presented herein describe a preliminary study utilizing advanced chemical detection techniques to identify the compounds that accumulate in the recycled water.

DESCRIPTION OF PROCESS

Figure 1 shows a flow diagram of the physical-chemical process designed for use aboard recreational vehicles or in isolated areas where water is in short supply (1). The process package is compact,

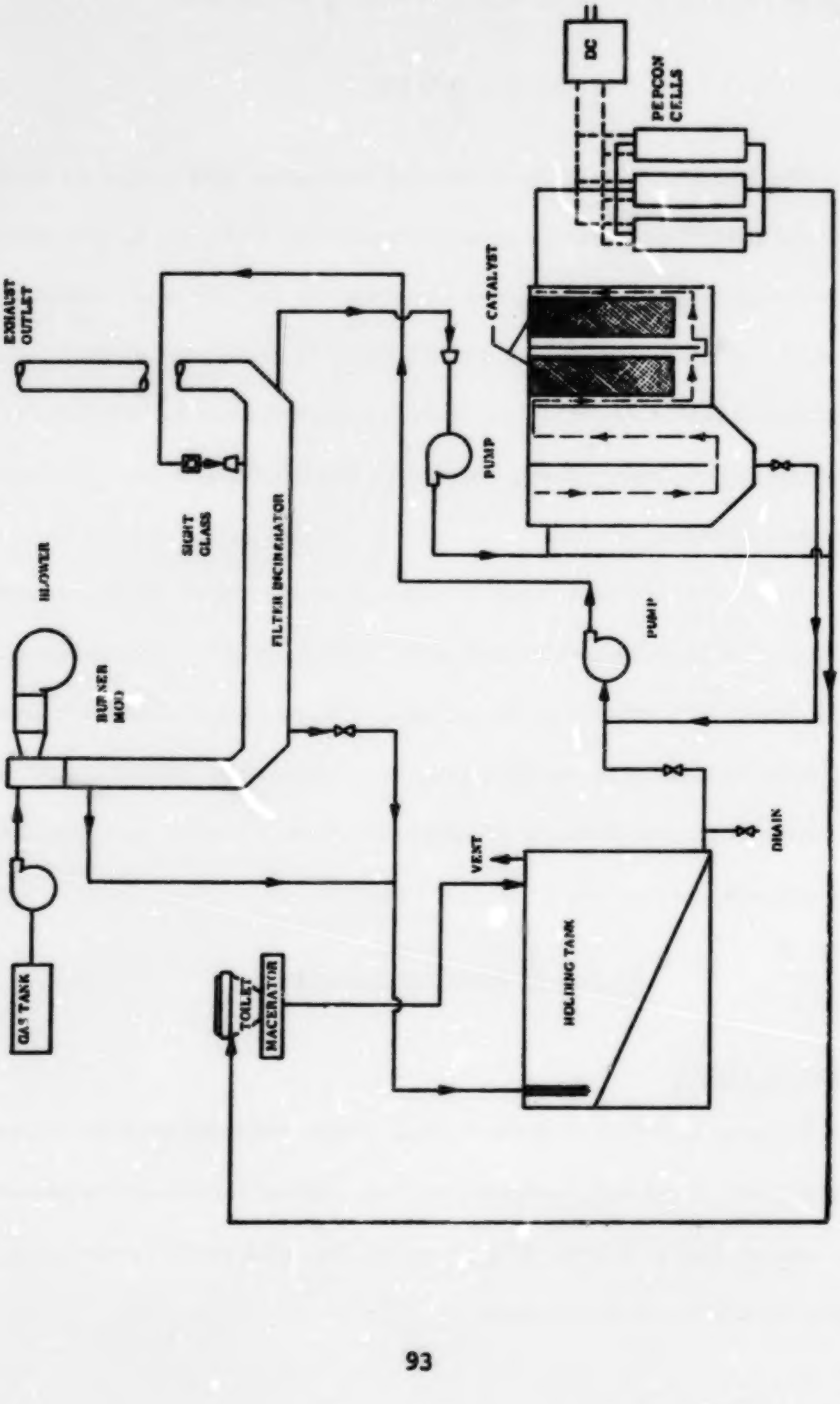

GAS TANK
FUEL PUMP
BURNER MOD
BLOWER
SIGHT GLASS
EXHAUST OUTLET
FILTER INCINERATOR
PUMP
PUMP
CATALYST
PEPCON CELLS
DC
VENT
DRAIN
HOLDING TANK
TOILET
MACERATOR

Figure 1. Small Pleasure Boat System Schematic

easily operated, requires little maintenance or operation, and can be operated seasonally without any variation in efficiency.

PROCEDURES

The sample used in the following evaluation was collected from a prototype unit treating wastewater produced by five people, and the unit had been operating for 40 days at the time the sample was collected. The waste system contained approximately 30 gallons of water. Additional detailed information about the operation of the process is contained in two letters from Thiokol Chemical Corporation personnel presented in the Appendix.

Direct extraction and extractions of concentrates of the treatment process effluent were performed with redistilled ether and chloroform using continuous extraction equipment. The products of these extractions were examined by nuclear magnetic resonance (NMR), infrared absorption (IR), the addition of alcoholic silver nitrate, and total and inorganic carbon analyses.

RESULTS AND DISCUSSION

Carbon Analyses

To establish that organic carbon compounds did exist in the process effluent, total and inorganic carbon concentrations were performed. As shown in Table 1, over 60 percent of the total carbon present in the sample was in the organic form.

Table 1

Distribution of Carbon Concentration in the Treatment Facility Effluent

Constituent	Concentration mg/l
Total Carbon	655
Inorganic Carbon	245
Organic Carbon	410

Ether and Chloroform Extractions

The first extraction was carried out for three days on approximately 500 ml of the treatment facility effluent using redistilled ether and continuous extraction equipment. The ether extract was then dried over magnesium sulphate, filtered and concentrated. A yellow-orange viscous liquid remained. Infrared (IR) and nuclear magnetic resonance (NMR) spectra were obtained for this liquid. The results are shown in Figures 2 and 3, respectively. Table 2 shows a summary of the interpretation of the spectra presented in Figures 2 and 3. The isolated liquid appears to be a complex mixture. The IR spectrum indicates the presence of -OH or -NH and -C = 0 functional groups. It also has strong absorption in the area for aliphatic -CH bonds.

The most intense signals given in the NMR spectrum occurred at $\delta = 0.88$ to $\delta = 1.63$ and indicates that the major portion of the mixture was of an aliphatic -CH nature. Peaks from δ 2.10 to δ 4.88 indicate substituted aliphatic type protons. The intensity of these peaks indicates that the substituted proton was present to a much lesser extent that the aliphatic -CH species. There was also an indication of some aromatic or-O$\underline{H}$ protons at δ 7.12.

Two additional extractions were made on the houseboat effluent. Approximately 2000 ml of effluent were concentrated to ≈ 190 ml using a roto flash-evaporator. Care was taken to keep the temperature under 35°C. Upon concentration to this point some solid materials (crystals, etc.) were observed. This concentrate solution was then

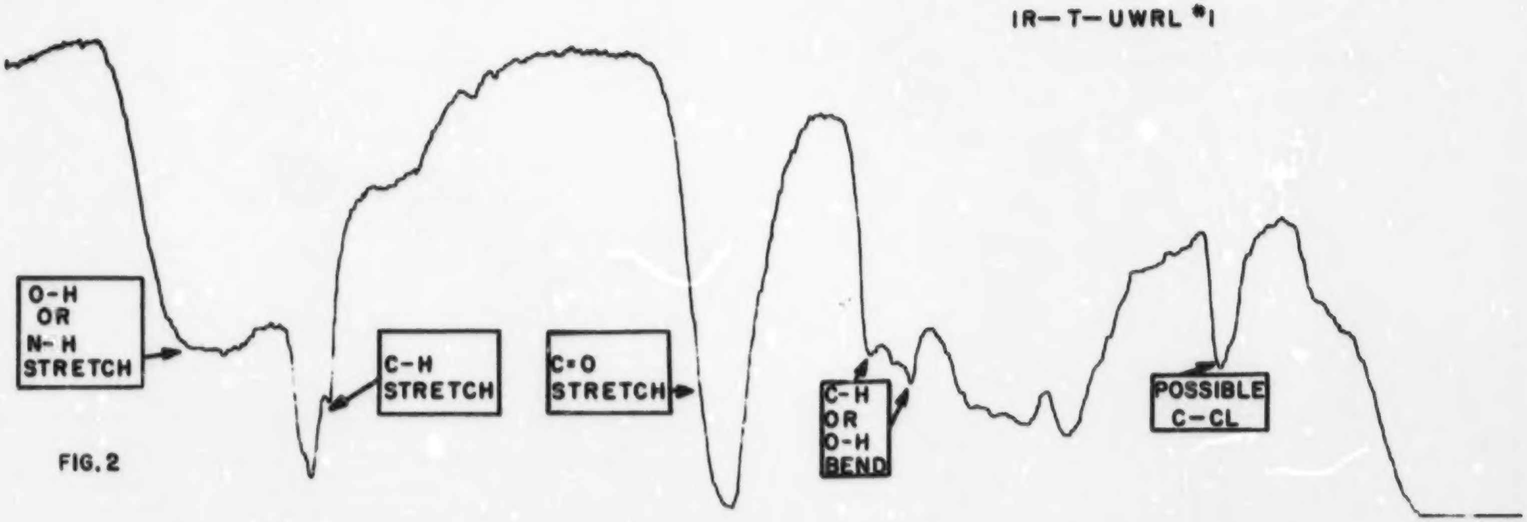


FIG. 2

Figure 2. Infared Spectrum T-UWRL No. 1

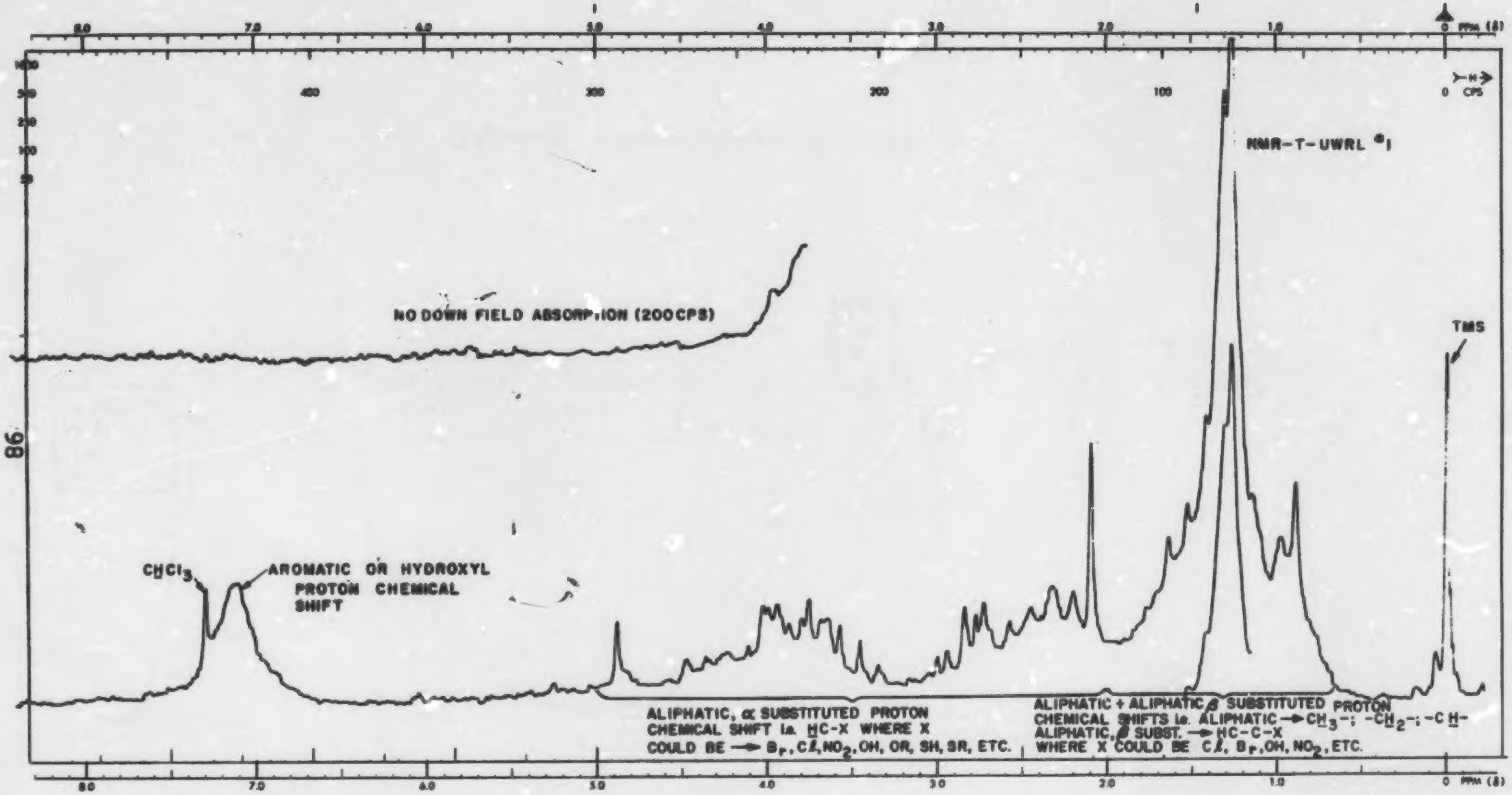


Figure 3. Nuclear Magnetic Resonance Spectrum T-UWRL No. 1

Table 2

Identification of Various Peaks in the Infrared and Nuclear Magnetic Resonance Spectra of Figures 2 and 3

Infrared Spectrum (Figure 2)

3250 cm^{-1}	Broad OH or NH STR
2880 cm^{-1}	Alkyl CH STR
2820 cm^{-1}	
1680 cm^{-1}	C = 0 STR
1420 cm^{-1}	Alkyl CH or OH Bend
1350 cm^{-1}	

Nuclear Magnetic Resonance Spectrum (Figure 3)

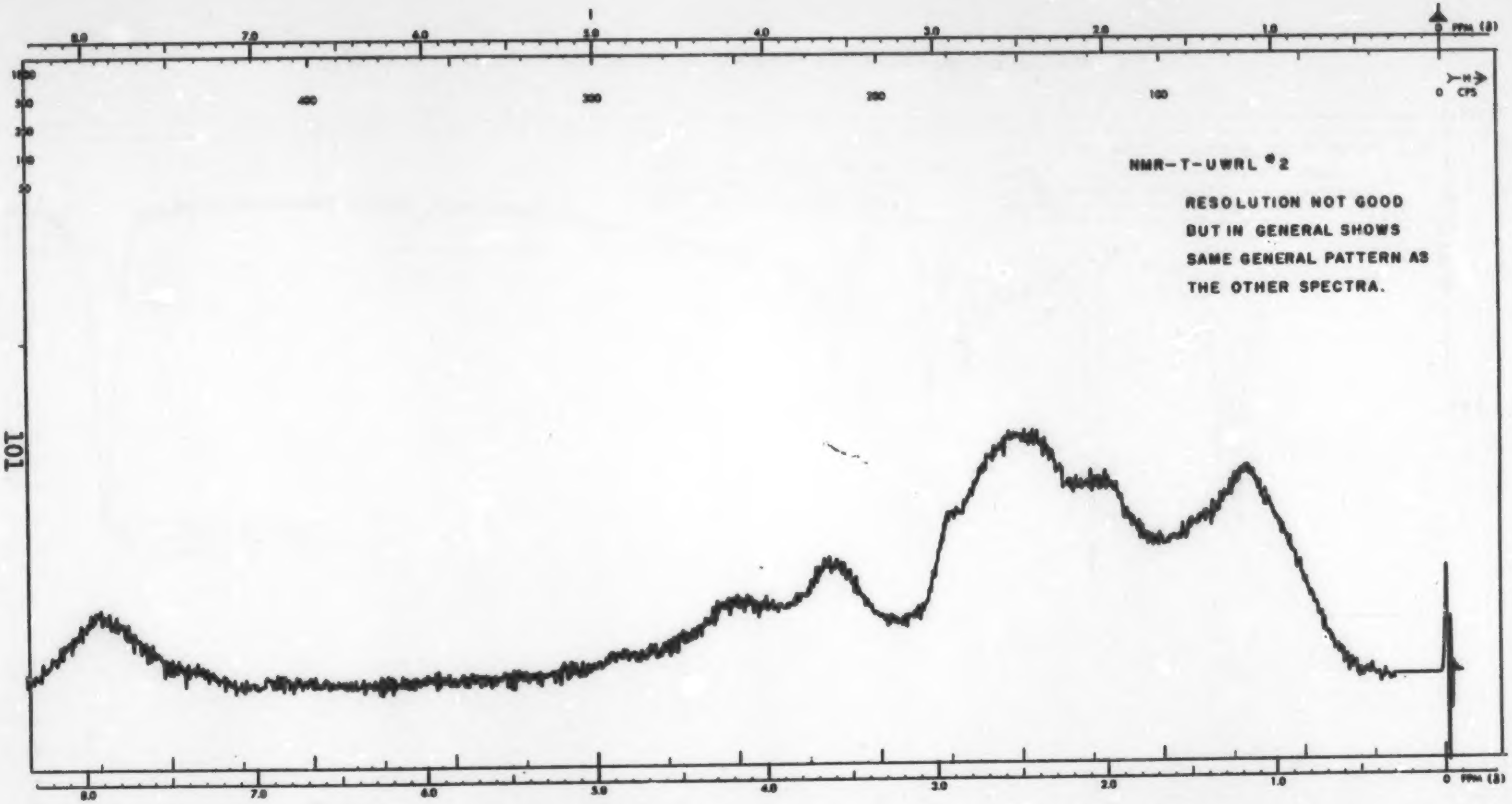
δ = 0.88		Aliphatic type proton chemical shifts and some with electronegative β-substituents
0.95		
1.14		
1.26		
1.42		
1.53		
1.63		
δ = 2.10		Aliphatic type proton chemical shifts with α-substituents. Some possibility of olefinic or acteylenic but not likely under the conditions used
2.20		
2.30		
2.40		
2.58		
2.72		
2.76		
2.84		
2.92		
3.00		
3.45	multiple peaks	
↓		
4.45		
4.88		
δ = 7.12		Aromatic or-OH type proton chemical shift

extracted with double-distilled chloroform for five days. The chloroform was then dried and evaporated leaving ≈ 0.1 g of a yellow-orange liquid. An NMR of this material was taken, but the spectrum was very poorly resolved (Figure 4).

Another 2000 ml of effluent were concentrated to ≈ 200 ml using the roto flash-evaporator. This concentrate was then extracted with distilled ether, and approximately 0.35 g of a yellow-orange liquid was obtained. The NMR spectrum (Figure 5) of this material was very similar to the one shown in Figure 3. The main differences occurred in the distribution and magnitude of some of the peaks. In the aliphatic region of δ 1.0 - δ 2.0 the peak intensities showed a decrease; whereas in the region of δ 2.1 - δ 4.0 there was an increase. Attempts to separate these aliphatic mixtures using thin-layer chromatography were unsuccessful.

Of the two distilled solvents used for extraction of the treated effluent, ether was found to be more efficient than chloroform. Concentration of the effluent apparently resulted in the loss of some volatile organics. Also, the possibility exists that the character of the constituents in the wastewater was modified by the procedures used to concentrate the samples. However, only accepted procedures were employed.

Complete extraction of the organic material is impossible because of inadequate solvent partition, solvent polarity, etc. To be sure that the best solvent for extracting the organics from the



NMR-T-UWRL #2

RESOLUTION NOT GOOD
BUT IN GENERAL SHOWS
SAME GENERAL PATTERN AS
THE OTHER SPECTRA.

Figure 4. Nuclear Magnetic Resonance Spectrum T-UWRL No. 2

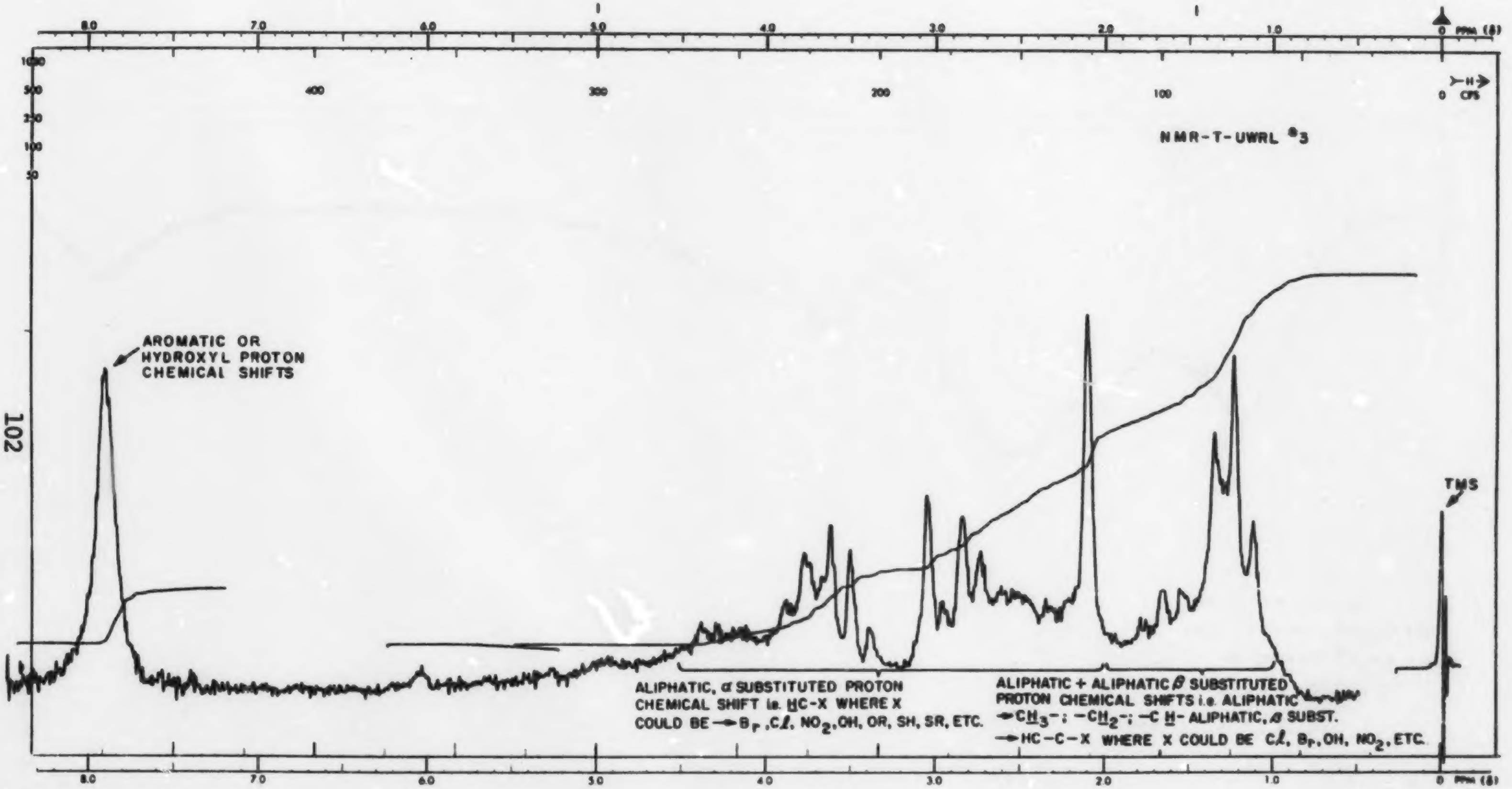


Figure 5. Nuclear Magnetic Resonance Spectrum T-UWRL No. 3

chlorinated effluent has been employed, it will require that many others be evaluated. However, ether does appear to yield good reproducible data that should give a good approximation of the types of compounds present in the effluent.

After the aqueous effluent material had been extracted, it was left out in the laboratory and growth appeared. This indicates that the compounds remaining after ether extraction are readily biodegradable and supports the results obtained by Middlebrooks (2) using a similarly chlorinated sewage sample.

Under the conditions used for treatment of the sewage effluent, the majority of the excreted nitrogen compounds (urea, amino acids, etc.) should be oxidized to lesser components.

Chlorination of most organic species should recur in the treatment process employed. Some free radical chlorination would proceed on alkane species present in the effluent and alkene type compounds would readily be converted by chlorine to saturated compounds which contain two atoms of chlorine attached to adjacent carbons.

Alcoholic Silver Nitrate Reaction

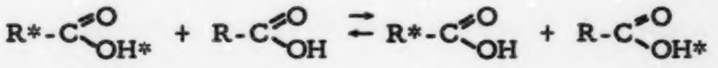
In many cases, the presence of halogen in an organic compound can be detected without a sodium fusion reaction. Organic halides react with alcoholic silver nitrate by the reaction below:

$$R{:}X + Ag^{+} \rightarrow R^{+} + \underline{Ag^{+}X^{-}}$$

The ether extract (yellow-orange viscous material) reacted with silver nitrate to give a white precipitate which upon standing turned grayish-black. The precipitate was not soluble in dilute nitric acid. Halogen was thus indicated.

Deuterium Exchange Reaction

A comparison of the downfield signal in the NMR spectra shows a slight variation between the different spectra which is unusual for aromatic protons. NMR adsorption by a hydroxyl or carboxylic acid proton (-O$\underline{\mathrm{H}}$, $\text{-C}\genfrac{}{}{0pt}{}{\nearrow \mathrm{O}}{\searrow \mathrm{O}\underline{\mathrm{H}}}$) ordinarily gives rise to a singlet in the NMR spectrum: its signal is not split by nearby protons, nor does it split their signals. Proton exchange between two molecules which contain hydroxyl or carboxylic acid protons is so fast that the proton - now in

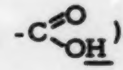


$$\text{R*-C}\genfrac{}{}{0pt}{}{\nearrow \mathrm{O}}{\searrow \mathrm{OH*}} + \text{R-C}\genfrac{}{}{0pt}{}{\nearrow \mathrm{O}}{\searrow \mathrm{OH}} \rightleftharpoons \text{R*-C}\genfrac{}{}{0pt}{}{\nearrow \mathrm{O}}{\searrow \mathrm{OH}} + \text{R-C}\genfrac{}{}{0pt}{}{\nearrow \mathrm{O}}{\searrow \mathrm{OH*}}$$

one molecule, and in the next instant in another - cannot "see" nearby protons in their various combinations of spin alignments, but in a singlet average alignment.

This particular characteristic can then be used to further identify hydroxyl or carboxylic proton containing species by a deuterium exchange reaction. Because a deuteron has a much smaller magnetic moment than a proton, it absorbs at a much higher field, and does not give a signal in the proton NMR spectrum. As a result, the replacement of a proton by a deuteron removes from an NMR spectrum the

signal from that proton as if there were no hydrogen at all at that particular position in the molecule.

A deuterium exchange reaction was performed and indeed (Figures 6 and 7), the downfield peak (δ 7.2) disappeared. The remaining part of the spectrum remains relatively unchanged. Thus, the peak seen downfield (δ 7-8) was not attributable to aromatic protons, but rather to hydroxyl or carboxylic acid protons ($-O\underline{H}$,  $-C\begin{matrix}{=}O\\ {-}O\underline{H}\end{matrix}$).

Ordinarily, the signal produced by a hydroxyl proton will occur in the range of δ 1.0 to δ 5.5, and a signal from a carboxylic acid proton in the range of δ 10.5 to δ 12.0. A hydrated carboxylic acid proton under certain conditions can be seen in the area of δ 6.5-8.5, a position intermediate between a water proton signal and carboxylic acid proton signal. Figure 8 shows the spectrum for a long chain fatty acid with a carboxylic acid proton signal at δ 12.3. Figure 9 shows the same sample hydrated with the intermediate signal appearing at δ 7.7.

CONCLUSIONS

Present evidence suggests that the material isolated by extraction techniques is a complex mixture which consists mainly of saturated chlorinated fatty acids. The presence of lipids in feces provides a significant quantity of material that would result in saturated chlorinated fatty acids. Lipids are in feces because dietary lipids are not quantitatively absorbed by the human body and direct excretion occurs

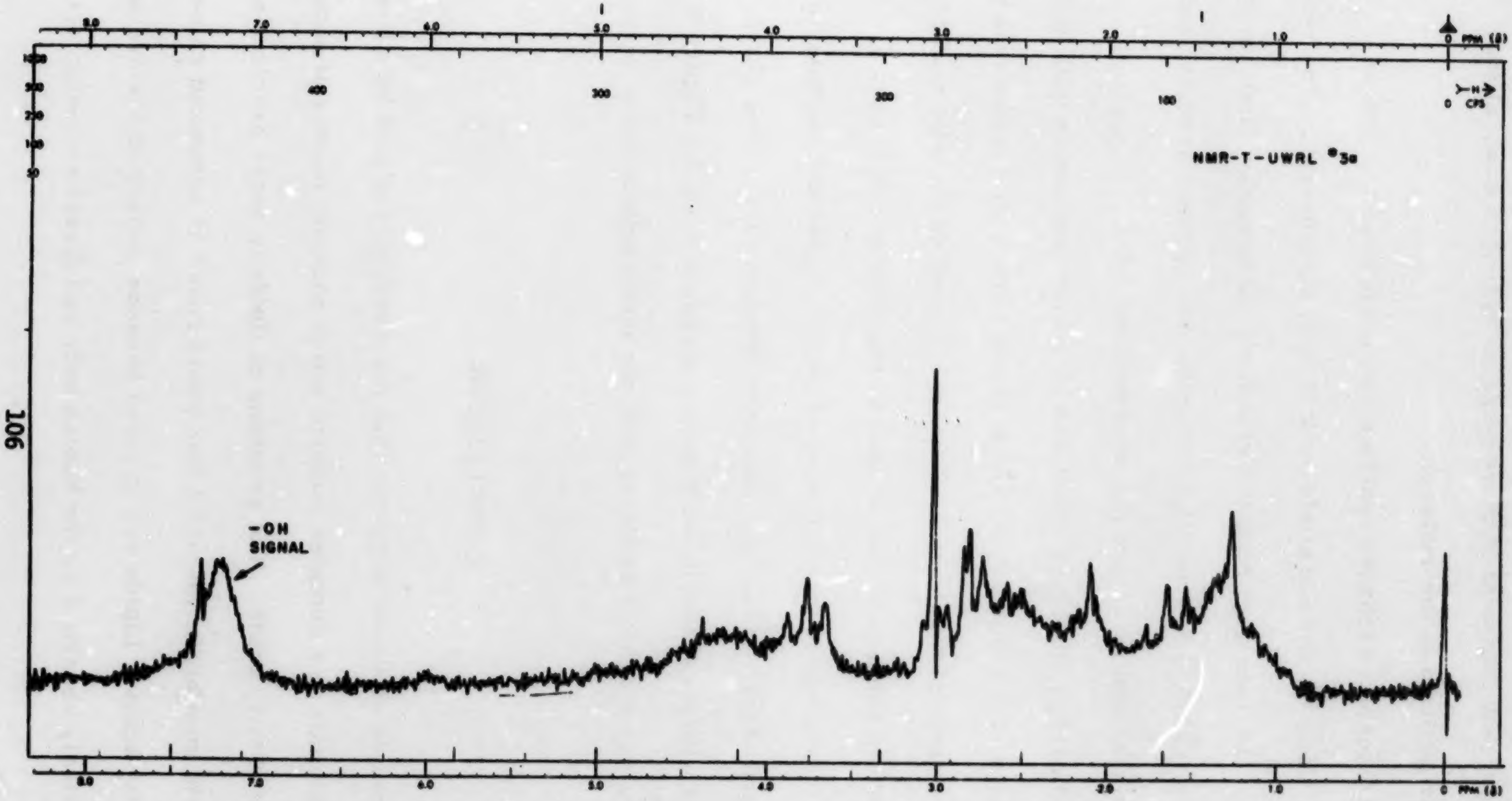


Figure 6. Nuclear Magnetic Resonance Spectrum T-UWRL No. 3a

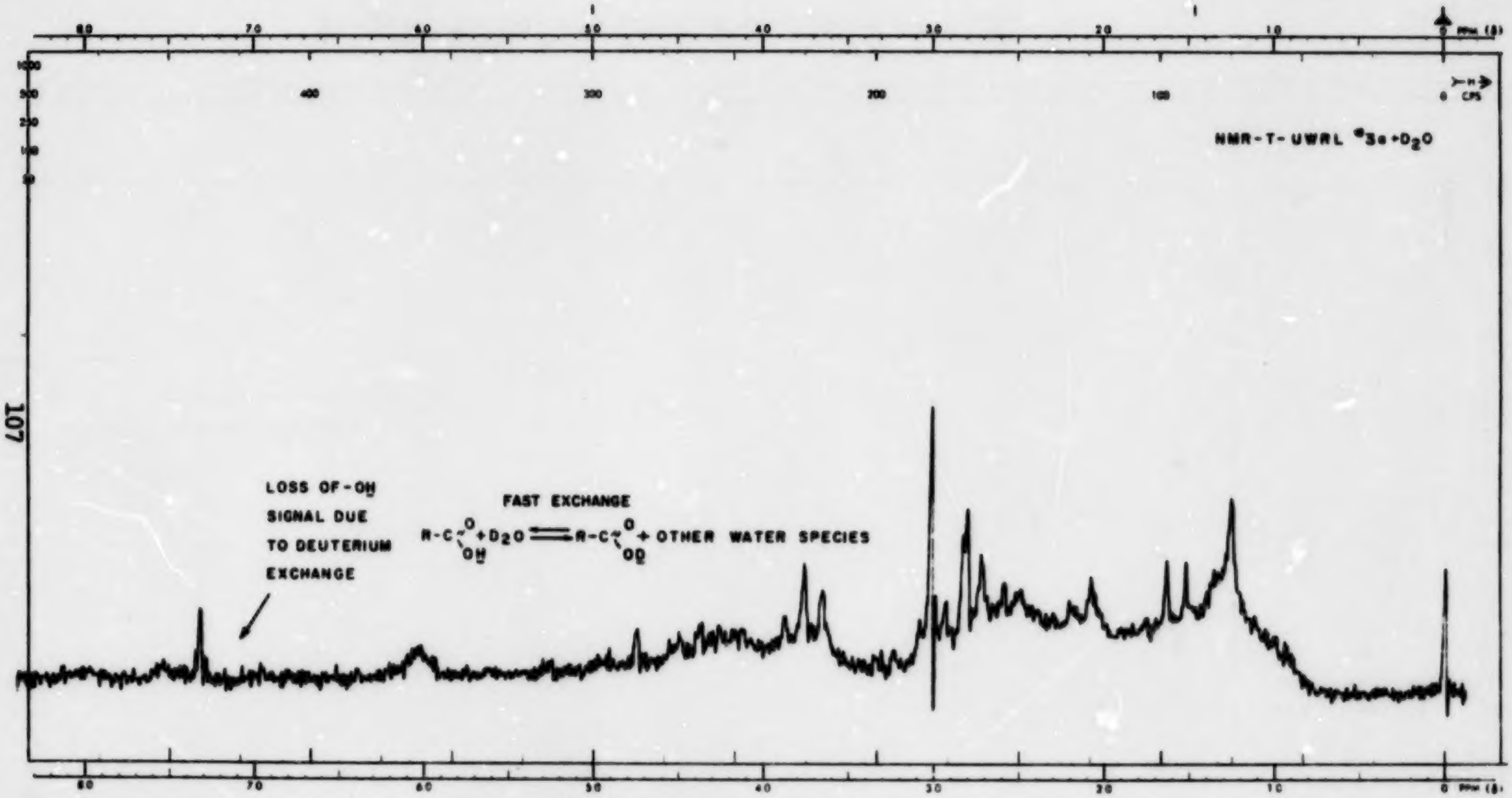


Figure 7. Nuclear Magnetic Resonance Spectrum T-UWRL No. 3a + D_2O

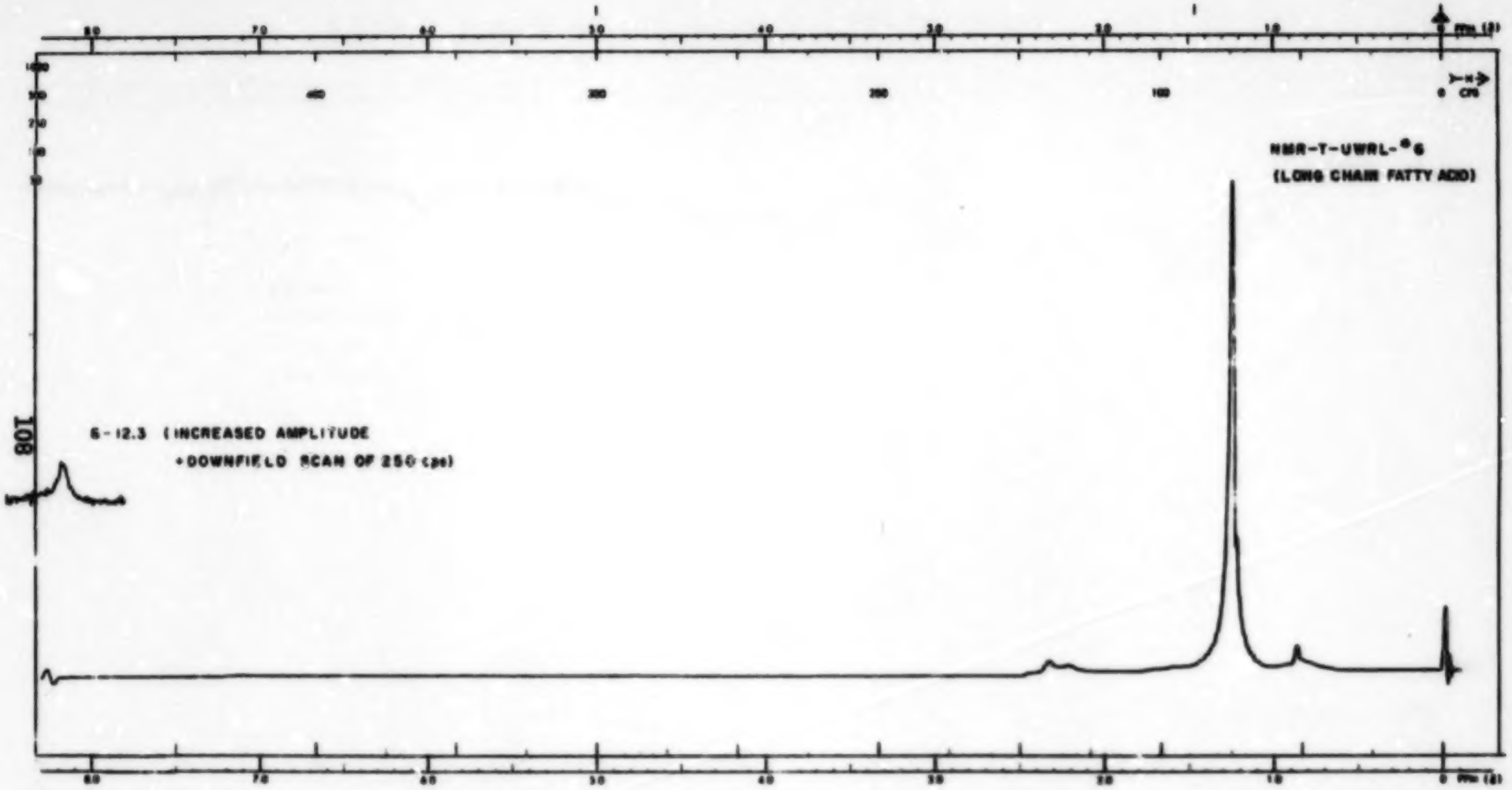


Figure 8. Nuclear Magnetic Resonance Spectrum T-UWRL No. 6

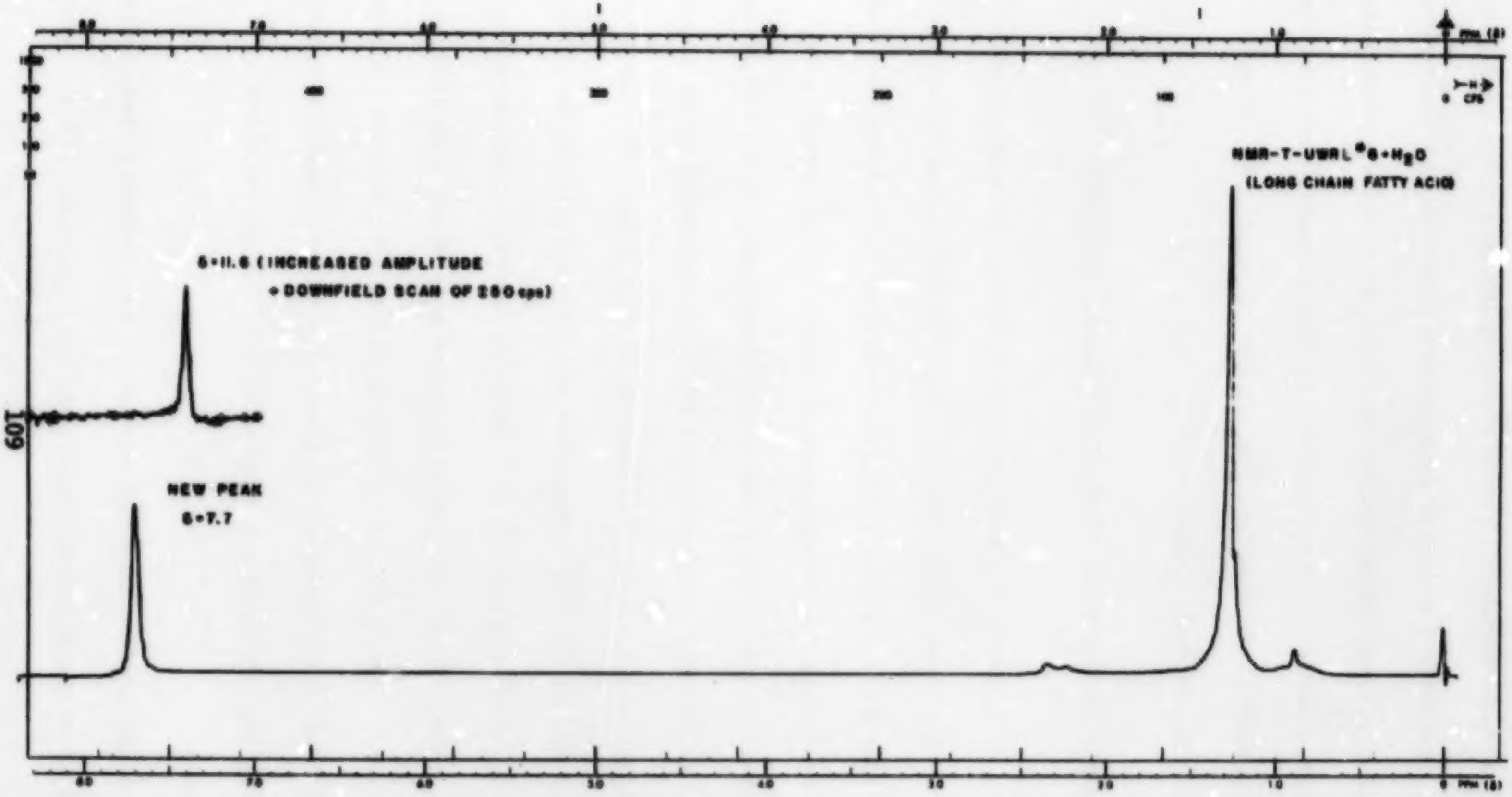


Figure 9. Nuclear Magnetic Resonance Spectrum T-UWRL No. 6 + H_2O

across the intestinal barrier. These excreted lipids are not as easily broken down or oxidized to lesser components as are the nitrogen type compounds (NH_3, urea, amino acids, etc.) in a high chlorine concentration treatment process. The treatment process probably converts the lipids by free radical chlorination and chlorine addition to give the saturated chlorinated fatty acids.

RECOMMENDATIONS FOR ADDITIONAL STUDIES

To further refine and specifically identify the types of volatile acids and perhaps other compounds that are not detectable by the solvent extractions used in this study, it is recommended that a wide range of solvents be evaluated. Although ether extractables apparently give well-defined spectra in both infrared and in NMR analyses, there are many other excellent solvents available, and perhaps several of these should be examined before accepting the conclusions of this study. The extraction studies could be expanded by completely evaporating effluent samples and then using Soxhlet apparatus to extract the residue obtained upon evaporation. Many other extraction techniques exist such as acid-base back extractions. There are an unlimited number of possible combinations of extraction techniques that could be further evaluated to specifically identify the compounds produced by the Thiokol recycled effluent process.

In all of the studies reported herein, it was assumed that complete reduction of all of the nitrogen compounds had occurred. This is very likely in view of the chemistry involved in the process; however, it would be prudent to analyze the nitrogen content in a sample of the waste to establish that all of the organic nitrogen has been destroyed. This is a relatively simple experiment and would have been performed in this series of tests if we had not exhausted our supply of effluent.

A highly desirable activity would be to conduct an extensive review of the literature with respect to reactions between high concentrations of chlorine and various types of organic compounds. It is quite possible that many pure compound studies have been conducted utilizing high concentrations of chlorine. If this is the case, it would make it very convenient to design experiments that would significantly reduce the work load in the event that additional studies are felt desirable by Thiokol.

Gas chromatography has not been applied to any of the extracts obtained in this study. Utilizing esterification in conjunction with gas chromatography could lead to the identification of several specific compounds in the effluent. Deuterium labeling of known and unknown compounds could also provide significant results.

The above mentioned techniques are just a few of the additional tests that could be performed on the effluent samples to further refine the identification of the organics remaining after treatment with high concentrations of chlorine. Table 3 lists some of the above and several additional techniques that might be employed in isolating the effluent compounds.

Table 3

Approach to Identifying Components of Highly Chlorinated Wastewater Treatment Plant Effluents

1. ISOLATION OF ORGANIC MATERIAL
    - a. Extraction (solvent partition)
      or concentration and then extraction
    - b. Lyophilization

2. SEPARATION AND PURIFICATION
    - a. Chromatography (thin-layer, column, gas, etc.)
    - b. Recrystallization
    - c. Sublimation
    - d. Distillation

3. IDENTIFICATION
    - a. Melting point or boiling point
    - b. Infra-red (IR)
    - c. Nuclear magnetic resonance (NMR)
    - d. Ultra-violet (UV)
    - e. Mass spectrometry (MS)
    - f. Gas chromatography (GC)
    - g. Carbon, nitrogen and hydrogen analysis

4. VERIFICATION
    - a. Comparison of properties with knowns
    - b. Synthesis

REFERENCES

1. Nance, P.D. and O'Grady, T.J., "Nonbiological Waste Disposal System," Thiokol Chemical Corporation, Brigham City, Utah. 1972.

2. Middlebrooks, E.J., Unpublished Data, 1973.

ADDENDUM
TO
APPENDIX II

P.O. Box 524, Brigham City, Utah 84302
801/863-3511

Thiokol / *WASATCH DIVISION*

12 December 1972
2690-72-117

Dr. E. J. Middlebrooks
Utah State University
Water Laboratory
Logan, Utah

Dear Dr. Middlebrooks:

With reference to our telephone conversation on 8 December, Orson Wilson will deliver 10 gallons of effluent to your laboratory this week.

The effluent had been in our closed loop waste treatment system being tested in our Building M-85. The waste system contained about 30 gallons of water and was handling the body wastes from about five people from 10 October to 20 November. The liquid was treated periodically during the 40-day run; treatment consisted of hypochlorite addition by means of a PEPCON cell (electrolytic production of hypochlorite from a NaCl solution). Solids were removed by rough filtration and incinerated.

On 22 November a run of 35 hours of PEPCON treatment was completed. The solution was "PEPCON treated" until it was colorless and a 1,140 ppm chlorine residual was measured. (Previous runs consisted of only several hours of PEPCON treatment, which did not decolorize the solution completely and gave chlorine residuals in the 300 to 500 ppm range.)

After the extended chlorine treatment a BOD of 712 ppm was measured. A similar 500 ml sample of system liquid was slugged with 10.5 grams of HTH, a chlorine residual of 3,000 ppm was measured after 1 hour of contact. The HTH treated sample had a BOD of 696 ppm.

The above results indicate to us that there exists a substance in our system that is not oxidized by hypochlorite and which can be utilized in a biological process. Please determine the identity of the BOD producing substance.

A DIVISION OF THIOKOL CHEMICAL CORPORATION

On 11 December the solution we are sending you had a 100 ppm Cl_2 residual. I assume there has been no biological activity in the liquid since the last BOD analysis was performed several weeks ago, however, I imagine you will want to perform a BOD analysis yourself to confirm the presence of a substance with a biochemical oxygen demand.

This work is to be performed under the recent waste treatment aid grant.

Sincerely,

Phil Woolhiser

P. H. Woolhiser

Thiokol / WASATCH DIVISION

15 January 1973
2690-73-010

Dr. E. J. Middlebrooks
Utah State University
Water Laboratory
Logan, Utah

Dear Dr. Middlebrooks:

Supplemental information to my 12 December letter follows as you requested during your telephone conversation with Dr. D. P. Clark on 11 January.

The 10 gal. water sample you received from us about a month ago was a portion of the water used as a flush medium in our closed-loop sewage treatment system in one of our plant buildings. The system received human waste material from 10 October to 17 November.

Initial system volume	32 gal.
NaCl addition	1,600 grams (1.33% by wt.)
Calcium Hypochlorite added (70% Cl_2)	243 g.
Lime added	120 g.
Cl_2 added by 10 in^2 PEPCON cells	1,230 grams (51-1/3 hr.)
Cl_2 added by 100 in^2 PEPCON cells	2,550 grams (42-1/2 hr.)
System temp during PEPCON treatment	90 to 100°F
System temp during idle period	70°F
Total events resulting in solids addition to the system	51
Total events resulting in only liquid addition to the system (does not include above 51 events)	285

After filtering the sewage, the solids remaining on the filter media are incinerated. Succeeding sewage batches enter the filter, contact the ashes from preceding incineration runs, and the filtrate runs into the treatment tank where PEPCON cells add hypochlorite. (Any possibility of the incineration performing a high temperature synthesis of organics which is washed into the treatment tank?)

The PEPCON treatment was segmented into one or two days of treatment each week. It wasn't one continuous run.

At the end of the use cycle (17 November), the system volume was just slightly more than the initial 30 gal. charge. About 1 gallon had been removed as samples during the run and an undetermined volume was lost by evaporation and incineration.

As you continue the evaluation of our system effluent, please inform us of any questions that arise.

Sincerely,

P. H. Woolhiser

cc: Dr. D. P. Clark